PART III.—COKING IN EUROPE.

HISTORY OF COKE IN ENGLAND.

But little is known concerning the history and the uses of coke in England until the beginning of the seventeenth century; but as it would be impossible to burn pit or mineral coal for domestic or any other purposes by the methods in use in early days in Great Britain without producing coke as cinders, in the same way that cinders were produced in burning wood, it is very probable that coke in the form of coal cinders was known at a very early day. It is proved beyond doubt that coal was used by the Romans during their occupation, and cinders of the Roman period are frequently met with. This view of the early use of coke is strengthened by the extract from M. Jars' work on metallurgy, quoted in the chapter on bee-hive ovens.

While it is probable that coke was not unknown at an early period in Britain, it by no means follows that it was made for use in the arts, either domestic or manufacturing, as the immense forests at that time would make it unnecessary to seek for a substitute for wood. The method of charring wood was well known in these early times, and the charred wood was a better fuel than the charred coal, so that there would be no inducement to use coke until charcoal should become scarce and high-priced. It is also well known that for many years a prejudice existed against burning "stones", as the coal was called, and in ignorant minds it was coupled with a species of witchcraft.

As the wood failed, however, the outcrop of the seams of coal would naturally be used, especially in the manufacture of iron, in which such large amounts of fuel were consumed, and it would be but natural to subject the coal, which was well known as a fuel, to the same treatment as wood, and coking in pits or mounds would be the result.

One of the earliest references to the coking of coal is in a patent granted to Thomas Proctor and William Peterson, in 1589, for making iron and steel and melting lead "with earth-coal, sea-coal, turf, and peat". The scheme proved a failure, two tons only having been made, so report says, at an iron works in Yorkshire, at a cost of 200 marks (£66 13*s*. 4*d*.) per ton. The chronicler quaintly remarks, "It is deere iron." In this patent is a distinct allusion to a preparatory treatment of the coal by "cooking". A short time after this, in 1590, a patent was granted to the Dean of York "to purify pit-coal and free it from offensive smell". In 1620 a patent was granted to a company composed of Sir William St. John and other knights, esquires, and gentlemen, with a Hugh Grundy, who was the "practical" man, for "charking" sea-coal, pit-coal, stone-coal, turf, peat, etc., and employing the same for smelting ores and manufacturing metals and other purposes. The project originated with Grundy, and referred specially to the making of coke by a process invented by him some time before.

About this time considerable attention began to be paid to the charring or coking of coal, not only in connection with the smelting experiments which were going on, but with a view to its employment for other purposes as well. In 1627 a patent was granted to Sir John Hacket and one Octavius de Strada (who two years before had been making attempts to smelt with coal in Hainaut) for a method of rendering sea-coal and pit-coal as useful as charcoal for burning in houses, without offense by the smell or smoke. A few years afterward (1633) another patent was granted to a company consisting of Sir Abraham Williams and others for a new way of "charking" sea-coal and other earth-coal, and for "preparing, dressing, and qualifying them so as to make them fit for the melting and making of iron and other metals and many other good uses".

During the next three or four years some eight or nine patents were granted for the employment of smokeless preparations of coal; and though the application of coke to the smelting of minerals was not successfully accomplished till long afterward, it came into use at this time for several other purposes, particularly for making malt. Houghton tells us that up to about 1640 the malt was made with straw fuel in Derbyshire, but that it then came to be made with coke, which occasioned an improvement in the quality of the brewings, "and brought about that alteration which all England admired."

A little later an attempt to substitute coke for coal in house fires was made by Sir John Winter. The project is referred to by Evelyn in his diary under date of 11th of July, 1656, in the following terms:

> Came home by Greenwich Ferry, where I saw Sir John Winter's new project of charring sea-coale to burne out the sulphure and render it sweete. He did it by burning the coals in such earthen pots as the glasse men mealt their mettal, so firing them without consuming them, using a barr of yron in each crucible or pot, which bar has a hook at one end, that so the coales, being mealted in a furnace with other crude sea-coals under them, may be drawn out of the pots sticking to the yron, whence they are beaten off in greate halfe-exhausted cinders, which being rekindled make a cleare pleasant chamber fire, deprived of their sulphur and arsenic malignity. What success it may have, time will discover.

Sir John sent some of his "cooked coal", together with a new-fashioned grate, to several great men for a trial, but his project did not succeed.

In 1662 Dr. Fuller wrote:

> It is to be hoped that a way may be found out to charke sea-coal in such manner as to render it useful for the making of iron. All things are not found out in one age, as reserved for future discovery; and that perchance may be easy for the next which seems impossible to this generation. (*a*)

a For many of these details I am indebted to the *History of Coal Mining*. R. C. Galloway. London, 1882.

Dr. Plot, in his *Natural History of Staffordshire*, published in 1686, states:

They have a way of charring the coal, in all particulars the same as they do wood, whence the coal is freed from those noxious steams that would otherwise give the malt an ill odor. The coal thus prepared they call "cokes", which conceives as strong a heat, almost, as charcoal itself, and is as fit for most other uses, but for melting, fining, or refining of iron, which it cannot be brought to do, though attempted by the most skillful and curious of artists.

Swedenborg, who was an able metallurgist, in his book on the *Subterranean Kingdom*, published in 1734, states that in certain districts in England coke was employed in smelting iron, and that cinders and coke were synonymous terms. This would indicate that the date (1735) usually given as that of the successful introduction of the smelting of iron with coke is erroneous.

Jars' statement, made in 1769, that coke was made in England, not only in heaps, but also in closed ovens, is elsewhere mentioned. His statement would lead to the belief that the method of coking in heaps was in use on the continent of Europe; a belief that is confirmed by the fact that the iron manufacturers of Liége, a short time after this publication, adopted with success the method of coking in closed ovens.

About the same time, according to Horne, (*a*) coking in ovens was carried on in the villages around London, the coke being prepared for the use of maltsters and for some other purposes. He gives the following description of the process:

These ovens being from time to time charged with a proper quantity of coals, they set them on fire. Near the front or opening of these ovens the chimneys are placed, at which outlets, when the coals become sufficiently ignited, the flames which play round the interior parts of the oven make their exit, carrying along with them a very considerable part of crude sulphur. The workmen employed at these ovens, when they imagine the coals are sufficiently burnt, draw them out with an iron raker upon the ground before the oven, where they endeavor to stifle the yet remaining part of the sulphur by quenching them with a deluge of water. Thus they go on charging, discharging, and suffocating till they have completed their intended quantity.

An experimental coke oven, on a plan proposed by Horne, was erected in Staffordshire, and, it is stated, with a successful result. The details of the plan are not given. It appears, however, that the oven consisted of a closed arched chamber, and that on trial it was found to be desirable to leave some outlet "in the top of the crown" for the escape of vapor, in order to prevent the blowing up of the oven. In 1781, according to Bishop Watson, the application of coke to the smelting of iron had become general in England, and coke ovens were in operation at Newcastle-on-Tyne, and even at Cambridge, where the coke was used for drying malt. (*b*)

It was this extension of the use of coke in the smelting of iron that gave its manufacture prominence. Up to early in the seventeenth century charcoal was the only fuel used in iron-smelting; but during the reign of James I several patents were granted for the exclusive right to manufacture iron with pit-coal, none of which were successful until 1619, when Dud Dudley succeeded and obtained a patent for fourteen years.

At this time many of the iron works were idle from want of wood. Remarking on the rapid exhaustion of the forests of England, Mr. David Mushet (*c*) estimates that the amount of charcoal necessary for the manufacture of iron alone in the year 1615 would be 28,063,000 cubic feet. Supposing an acre of ground to afford 2,000 cubic feet of timber, he estimates that 14,031 acres of land were annually stripped to supply the iron manufactories. Though pit-coal had been mined at Newcastle prior to 1272, and vast quantities of it had been annually exported to Holland and the low countries for the use of the smithies and other manufactories requiring an intense and continued heat, yet in England prejudice was very strong against its application to the manufacture of cast or malleable iron, and smithies and nail forges and manufactories of every sort were still carried on by means of charcoal. As a result of this the price of iron advanced, and those manufacturers whose supply of wood was undiminished were, of course, hostile to any improvements by which other fuels could be used.

Dudley continued his experiments with pit-coal with varying success and under many discouragements for a number of years. Other patents were also taken out for the manufacture of iron with coal, in one of which, that of Captain Buck, it is believed Cromwell was a partner. In 1663 Dudley applied for his last patent, setting forth in his application that at one time he was able to produce 7 tons of pig-iron weekly. His uncommon success produced combinations against him, which terminated in hostile attacks upon his works. This rivalry in the business, and his attachment to the royal cause during the civil war, brought successive misfortunes upon him, and interfered with the use of his improvements, and the refusal of a new patent after the restoration prevented him from again entering into the business.

Mr. I. Lowthian Bell, the well-known authority on blast-furnace phenomena, believes that if Dudley had met with encouragement instead of persecution he would ultimately have been led to treat mineral fuel as they had previously done the vegetable, viz, char it. (*d*)

Though Dudley's last application for a patent was in 1663, his experiments really ceased in 1657, and from that time for nearly eighty years the art of making iron with pit-coal was lost. Abraham Darby's invention of the use of coke in blast-furnaces completed the work of his unfortunate predecessor, though in the meantime efforts

---

a *Essays concerning Iron and Steel*, by Henry Horne. London, 1773.

b See *Percy's Metallurgy*, London, 1875, page 416.

c *Papers on Iron and Steel, Practical and Experimental*, by David Mushet. London, 1840.

d See *Chemical Phenomena of Iron Smelting*. London, 1872.

to use coal had not entirely ceased, and in some cases even coke was used in the blast-furnace. Leigh tells us in his *Natural History of Lancashire* that shortly before 1700 iron was being made "by means of cakes of pit-coal" (*i. e.*, coke).

It is generally conceded that the credit of the first successful and continued use of coke in the blast-furnace is due to Abraham Darby. The date of Darby's invention seems in doubt, (*a*) some authorities placing it as early as 1713, others about 1735, and still others at 1750. The statement of Swedenborg, before referred to, would indicate that it must have been at least as early as 1735, and this is the date usually assigned.

Percy thus describes his experiments: (*b*)

Young Abraham Darby entered upon the management of the Coalbrookdale Iron Works about 1730. As the supply of charcoal was fast failing, Abraham Darby attempted to smelt with a mixture of raw coal and charcoal, but did not succeed. Between 1730 and 1735 he determined to treat pit-coal as his charcoal-burners treated wood. He built a fire-proof hearth in the open air, piled upon it a circular mound of coal, and covered it with clay and cinders, leaving access to just sufficient air to maintain slow combustion. Having thus made a good stock of coke, he proceeded to experiment upon it as a substitute for charcoal. He himself watched the filling of his furnace during six days and nights, having no regular sleep, and taking his meals at the furnace-top. On the sixth evening, after many disappointments, the experiment succeeded, and the iron ran out well. He then fell asleep in the bridge-house at the top of his old-fashioned furnace, so soundly that his men could not wake him, and was carried to his house, a quarter of a mile distant.

While the change in fuel from charcoal to coke was being brought about the manufacture of iron in England declined so rapidly that in 1740 the number of furnaces was only 59, a reduction of 25 per cent., and the make of pig-iron only 17,350 tons. The production rapidly advanced, however, under the stimulus of Darby's discovery, until 1788, when of 61,300 tons of pig made 48,200 were smelted with coke and but 13,100 with charcoal. It is also but just to state that Watt's improvements in the steam-engine, and the great changes that took place about this time in the form and construction of furnaces, contributed to this advance. At the present time little or no charcoal iron is made in Great Britain.

We have entered thus fully into the history of the progress of the manufacture of pig-iron with coke, as this industry and that of coke-making are so closely identified that it is almost impossible to state the history of one without making it also a history of the other. Outside of the use of coke in the iron industries its consumption is but comparatively small. In all attempted improvements in ovens and methods of manufacture of coke the ruling question as to their adoption is, "What kind of a blast-furnace fuel is the resulting coke?" and as the coke is improved or injured for this purpose by the new methods the improvements have been adopted or rejected.

As has been already stated, the earlier method of making coke in heaps or mounds soon gave place, as the demand for coke for iron-smelting increased, to the bee-hive oven, and this in turn, in some countries, though to no great extent in England, to the improved form of ovens commonly known as the "Belgian". These changes and improvements will be treated of under their appropriate heads.

In addition to these changes methods have been adopted for utilizing the waste heat of the ovens for raising steam, and, as is stated in the chapter on the utilization of waste products, for utilizing the ammonia and tar from the waste products of combustion. In at least one case, also, these waste gases, having first been enriched, are used for lighting purposes.

Outside of the improvements already noted but very few changes have been made in the methods of operating the ovens, and these mostly in the line of greater economy in charging the coal, discharging the coke and watering it, and loading it upon cars. "Hoppers," "trolleys," and "larries" have been substituted for charging the ovens, instead of the old plan of throwing the coal through the door by means of shovels, drags and mechanical rams for discharging the ovens have taken the place of hand-labor and a hook, and the coke is quenched with a hose and nozzle instead of the primitive bucket. In the management of the oven, also, practically three levels are used, the first or highest containing the track on which the charging larries are run, the second on a line a little below the bottom of the oven, called the "coke-wharf" in this country, upon which the product of the ovens is discharged, while the third level, a little lower still, is occupied by the railroad, the top of the cars being on a line with the wharf, thereby giving greater facility for loading. It is impossible to follow chronologically the course and the development of these improvements; the best that can be done is to indicate their results.

COKING IN GREAT BRITAIN AND IRELAND.

No complete statement of the present condition and extent of the manufacture of coke in the United Kingdom has been obtained; indeed, it is doubtful if such a statement exists in any form accessible to the public. Coke is generally regarded as a form of coal, and its statistics are included with those of coal, the coke sometimes being reduced to its supposed equivalent in coal and sometimes not. Even the *Mineral Statistics of the United Kingdom* furnish no complete statistics, nor do they give data from which even the make of coke can be estimated. Coal and coke are usually reported together, but the exports of coke are given separately. It is possible to

---

a See *Jevon's Coal Question;* also Scrivenor's *History of the Coal Trade*, which puts it at 1713. Mr. M. M. Johnson, of the Kingswood colliery, England, in a lecture delivered before the Bristol Mining School, published in the *Colliery Guardian* of February 2, 1877, page 161, also gives the date as 1713.

b *Percy's Metallurgy*, "Iron and Steel," page 888.

estimate the consumption of coke in the blast-furnaces of certain districts, and some of the railroads distinguish between the coal and coke carried over their lines, but in the tables of total production coke disappears. Statements as to the amount of coke consumed in certain industries are sometimes published, but all such statements, as well as those professing to give the output for certain districts, are only estimates more or less accurate, while statements showing even the estimated total production of the United Kingdom for recent years are almost, if not quite, wanting.

Notwithstanding this dearth of positive information regarding English coke, sufficient is known to warrant the classification of its manufacture among the important industries of Great Britain; important, not only by reason of the aggregate tonnage produced, which must be considerably in excess of 6,000,000 tons gross annually, but also because of the wonderful development of the British iron trade which its manufacture has made possible. The pre-eminence of Great Britain in the manufacture of iron is due to its possession of abundant deposits of coal. When the kingdom had been well-nigh stripped of its forests to furnish charcoal to smelt its iron ores, and the high price of pig so smelted promised to send this manufacture at least to countries having abundant supplies of charcoal, it was Darby's invention or rediscovery of the use of coke for smelting that gave to its blast-furnaces a new life, reduced the cost of pig-iron, and retained its manufacture in Great Britain. As other countries have advanced in the manufacture of iron, there can be no question that the United Kingdom has retained its pre-eminence in the iron markets chiefly by reason of the excellence, abundance, and cheapness of its coke. These have made possible the utilization of its low-grade ores in the production of pig-iron at a low cost, and have rendered feasible the continued competition of English iron with that of other nations, not only in the general markets of the world, but often in the home markets of these nations.

The most important coking district in Great Britain, and consequently in the world, is the Durham, which lies in the northeastern part of England. The production of this district is not only largely in excess of that of any country in the world, but the Durham is a typical blast-furnace coke, bright, resonant, cellular, and low in ash and other impurities. Taking the average of numerous analytical results of the best varieties of Durham coke, 6 per cent. of ash and about 0.60 per cent. of sulphur may be considered as the proportion of these constituents.

As to the extent of the Durham coal-fields that produce the coking coal there seems to be some difference of opinion. Mr. T. Y. Hall, in a paper published in the proceedings of the North of England Institute of Mining Engineers, includes in this field the coal-seams from Etherly on the south to Wylam on the north, an average distance of 20 miles long by about 8 wide, or 160 square miles. Mr. A. L. Steavenson, however, in a paper read before the Iron and Steel Institute of Great Britain, states that the field of coking coal extends from Bradbury station, on the Northeastern railway, on the south to Gateshead on the north, 23 miles long by 11 miles wide, or 253 square miles. Mr. Steavenson is probably more nearly correct than Mr. Hall, the difference in the estimates arising probably from a difference of opinion as to the classification of the coal in certain seams.

The typical Durham coal is high in carbon, low in sulphur and ash, and with but little care or preparation burns into a most excellent coke. The best coal is obtained from the lower seams. The Brockwell and Busty seams, in the Brancepeth district, may be taken as fairly representing this coal. The analyses of these coals, are as follows:

Constituents.*	BUSTY SEAM.		Brockwell seam.
	Upper part.	Lower part.	
	Per cent.	*Per cent.*	*Per cent.*
Carbon	81.22	78.46	83.40
Hydrogen	4.70	4.42	4.40
Oxygen and nitrogen	9.45	8.82	7.18
Water	0.85	0.99	0.90
Ash	3.28	6.17	3.50
Sulphur	0.81	1.83	1.00
Total	100.31	100.69	100.38

*Authority, I. Lowthian Bell.

The coal of the above seams yields from 60 to 65 per cent. of its weight of coke. Its purity will be seen from the appended analyses of the coke made from the seams in the following collieries:

Collieries.	Carbon.	Ash.	Sulphur.	Water.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Hamsteels	92.55	6.36	0.81	0.21
Consett	91.88	6.91	0.84	0.37
Whitworth	91.56	6.69	1.21	0.54
South Brancepeth	93.41	5.30	0.91	0.36

This coke is extremely hard and strong, and is capable of resisting a very high column in the blast-furnace, a cube 2 inches square, made at the Clarence iron works, having supported a weight of 25 hundred-weight when cold and 20 hundred-weight when hot before it was crushed.

The oven used, almost without exception, is the bee-hive, and at some works are larger than those used in this country. At the Consett iron works they are 11 by 11½ feet. At the Browney colliery an oven with flues similar to those in Cumberland and other districts is used, and at least at one works the Carvés oven is used. The bee-hive oven, though not giving as high a yield as others, is believed to produce the best coke for iron metallurgical purposes. The coal, however, cokes readily, and produces a good fuel without much care. There are from 15,000 to 16,000 of these ovens (*a*) in use in Durham, in which about $5,000,000 are invested. (*b*) The time of burning varies from 24 hours to as high as 120 hours, according to the weight of the charge and the use to which the coke is to be put. Shipping and smelting coke is burned from 72 to 96 hours; the Silkstone coal, crushed and washed, when intended for use in steel works, is burned from 72 to 80 hours.

The annual production of coke is estimated by Mr. Meade at 4,000,000 tons, (*c*) and the value as exceeding $10,000,000. Coke-drawers to the number of 2,000 were employed. Mr. I. Lowthian Bell estimates the output of coke of the counties of Durham and Northumberland at 6,000,000 tons annually, and his opportunities for making an estimate are so good that the statement may be accepted as correct. In this case more than 2,000 drawers would be employed. A good man can draw coal and do a share of the charging of six ovens. The coke is not only largely used locally in locomotives and the various operations of iron-making, but is largely exported to other districts of England and to foreign countries, and is chiefly used in iron smelting, though the hard-burnt is used in Sheffield to some extent in melting crucible cast-steel in the form of steel furnaces known as "coke-holes", or "coke-furnaces".

In recent years the quality of Durham coke has not been so uniformly good as formerly. Not only has considerable coke been made from washed coal, but some seams are now used for coking that formerly were not regarded as sufficiently pure for the purpose; at least the coke could not compete with that made from the best seams of coal. Mr. E. Windsor Richards, in a paper read before the Cleveland Institute of Engineers, in November, 1880, remarks that there was no hiding the fact that large tracts of the best coking coals in the county of Durham had been worked out, and though there was still a very large quantity of good coking coal left, yet some of the inferior seams were being largely worked with very little attention to the cleaning of the coal. Attempts are made in many cases to reduce the impurities to a minimum by crushing and washing, but even this is not successful. The washer used is the old trough type, which is not only wasteful of coal, but is an imperfect separator.

Concerning the other districts of England in which coke is made, still less information is obtainable than concerning Durham. In none of them is the coal so well adapted to coking or so pure as Durham, and the coke produced is not as good, especially for use in the manufacture of iron. In most of these districts but little attention was paid to the production of a good quality of coke until within the past few years, when colliery owners found that it would pay to make coke suitable for iron-smelting. The best appliances are now being introduced, and the manufacture of it is extending in the districts outside of Durham, and, by using care in its production, a very good quality is made, which is not only consumed in the local iron works, but is shipped to other districts of England and to foreign countries.

It must be borne in mind, in speaking of the character of the cokes of other districts as compared with the Durham coke, that the latter is an extraordinarily good and pure fuel, and while the cokes of all of the other districts are inferior as compared with Durham, yet, as compared with those of France or Belgium, they are in many cases equal, if not superior.

It is also worthy of note in this connection that the production of coke is not now confined to those districts and seams which yield the best coking coal. The introduction of recent improvements in the manufacture of coke has enlarged the area, permitting its production from coal that would have been previously rejected as unfit for that purpose.

Next to Durham the most important coking district is South Wales. The manufacture of coke is here carried on quite extensively, the greater part of which is used in the manufacture of Welsh iron, copper, and tin, though some is sent to other districts of Great Britain and to foreign ports.

The coals of this district vary considerably in their composition, the seams occupying the northeast side of the Welsh basin being chiefly coking or semi-bituminous, those of the northwest anthracite, while the seams in the

a The *Pall Mall Gazette* estimated them at 16,000 in 1879. Mr. Steavenson's estimate in 1877 was 14,000.

b *The Iron and Coal Industries of the United Kingdom*, page 15. I am informed by a gentleman who has had considerable experience in building ovens in this district that the cost of a 11-foot oven in 1869 was about £25. In 1876 the contract price at the Brythorpe colliery was "£52 odd".

c The *Pall Mall Gazette* in 1879 estimated the production at 5,000,000 tons and the number of coke-drawers at 1,700, each drawing 2,800 tons a year. Thirty years before, the production of all England was, according to the *Pall Mall Gazette*, 2,500,000, and twenty years before 3,500,000 tons.

center of the coal-field are semi-bituminous. Truran gives the following analysis of a coal from the northeast side of the basin near Pontypool, which was used for coking:

	Per cent.
Carbon	80.4
Hydrogen	5.7
Oxygen	5.3
Nitrogen	1.2
Sulphur	0.9
Earthy materials	6.5

Specific gravity, 1.29; yield of coke, 66 per cent. The earthy matter shows the portion of ash. (*a*)

Of the coal that is classed as coking some seams yield a very good quality of coke without washing, but with much of the coal a previous washing is necessary to give a coke of sufficient purity and freedom from ash to be desirable as a furnace fuel.

The oven used most generally in South Wales differs from that in use in Durham, the latter being, as before stated, of the well-known bee-hive form, while the Welsh oven is a modified bee-hive, almost rectangular, and is adapted to discharging by mechanical means. As generally built this oven is about 14 feet long, 5 feet high, and 6 feet wide at the front and 5 feet at the back, this difference between the width of the front and back being to allow of ease in drawing the charge. The coke is drawn by means of a windlass attached to a wrought-iron bar laid along the length of the oven, another being laid transversely across it at the back, both being placed in position before the oven is charged. The ovens are generally built back to back, with a chimney between, sometimes with side and bottom flues, the Welsh oven in these respects anticipating the Belgian, and are in some cases charged through the top, in others through the door. The coke is sometimes cooled in the oven and sometimes after it is drawn.

The charge is about 4¼ tons for the first three days in the week and 5 tons for the remaining four days. For the coking of the smaller charge 72 hours are generally allowed, and for the larger 96. As is noted elsewhere, at the Ebbw Vale, Dowlais, and other works the Coppée oven has been introduced.

As is stated in another chapter, the manufacture of coke in the ordinary way in South Wales, although exceedingly hard and dense fuel is produced, does not appear to have attained all the economical results possible. Experience has shown that the carbonization of the coal is not complete, the long, deep fissures in the coke thus manufactured exhibiting, on examination, a considerable amount of dark carbonaceous matter not carbonized.

No statistics of the output of coke or of the number of ovens in this district have been obtained.

Considerable coke is also made in Lancashire, though the coal is even less adapted to coke-making than either the Durham or the South Wales, and most of it is crushed and washed before coking. At the works of the Wigan Coal and Iron Company the slack from their extensive pits is coked after being washed, the coking being done in 8-ton ovens, the process occupying five days. Some Coppée ovens are also used in this district with good results.

I am indebted to the kindness of Mr. W. H. Hewlett, of the Wigan Coal and Iron Company, limited, for the following description of this field:

The coke district of Lancashire is divided into two parts, southwest Lancashire, of which Wigan may be considered the center, and which is some 23 miles from Liverpool, and northeast Lancashire, of which Burnley may be considered the center, some 45 miles from Liverpool.

Beginning with the former we take first the nature of the coal from which coke is produced.

The coke here is made altogether from slack (that is, riddlings which pass through a mesh of three-quarters of an inch) from the Arley mine seam. This seam, a bituminous coal, is the bottom seam of the Wigan district (save the mountain measures, which are too thin here to be profitably worked), and varies in depth in the district from some 140 to 800 yards. The coal from the seam is used, the largest for house purposes, the next size for gas purposes, and the slack, as hereinbefore named, for the manufacture of coke.

The following may be considered a good average analysis of the quality:

	Per cent.
Ash	4.40
Sulphur	1.60
Volatile matter	32.15
Fixed carbon	62.21

To make this slack into coke there are something like 1,700 ovens in this district, of which the company I represent owns about 700.

The slack is washed to remove pyrites and dirt, and is at the larger works (our own, for instance) crushed afterward before being coked.

The following may be regarded as a fair average analysis of the coke produced:

	Per cent.
Ash	8.70
Sulphur	1.26
Volatile matter	0.90
Water	0.75
Fixed carbon	88.46

The ovens are bee-hive almost entirely. The coke is used principally at blast-furnaces, but commands some trade among the founderies in the neighborhood.

In the Cumberland district, where there are large deposits of rich hematite ores, most of the coke used is brought from Durham, at a cost of (June, 1880) from 8*s.* to 10*s.* a ton for freight alone. It is stated that 1,000,000

---

a Truran *On the Manufacture of Iron*, third edition (London, 1865), page 11.

tons of coke were used at the iron works of this district in 1877, of which but 50,000 were made in the district. Though the coal of Cumberland has an excess of ash and is high in sulphur, it is believed that both of these can be much reduced by careful washing and coking. The Coppée oven, which is especially designed for coking finely-divided coals, is being used successfully, though ordinary ovens are used also. In 1878 and 1879 there was considerable activity in the Cumberland coal-field in building ovens and making coke. At this date three or four seams of coal were worked in the West Cumberland coal-field from which coke was made. A large part of the coke, however, was made from slack or screenings and small coal, generally washed. The largest coke manufactory at the time was at the Clifton colliery of the West Cumberland Iron and Steel Company. Early in 1879 this company had 92 ovens at work and were making about 26,000 tons of coke from 46,000 tons of coal, the coal being crushed and washed at an expense of 5*d.* a ton. There were also coke ovens at several other collieries. These ovens, while they were built somewhat on the bee-hive plan, differed from the ordinary bee-hive in being built back to back with large flues between the backs running the entire length of the row, each oven having a connection with this flue, the flue being connected at the end with a large chimney. The ovens are charged through the top and drawn in the ordinary way.

In some cases the waste gases from the oven, after passing through the flues and before passing into the chimney, are conducted under boilers and the waste heat is utilized, these boilers supplying steam for working the machinery in crushing and preparing the coal, for the engines pumping the water from the pits, and in drawing the coke, where mechanical means are used.

The great coal-field which occupies so large an area of Yorkshire is the most continuous of the coal-fields of Great Britain, its length from north to south being upward of 66 miles and its breadth from 5 to 20 miles. Sheffield occupies the center of this great body of coal. In the southern part of Yorkshire the great seam is the Barnsley, which far exceeds in thickness any other of the known seams, except the Silkstone. This latter seam is the most highly prized in the Yorkshire field. Indeed, these two are practically the only seams wrought, and it is probable that no others will be touched, except for local consumption, until they are exhausted.

It is from the "smalls", or the fine coal of these two seams, that practically all the South Yorkshire coke is made. Up to a few years ago the production of coke was limited to the requirements of the Sheffield trade, chiefly for steel melting; but with the development of the Barnsley coal and the contemporaneous discovery of the oolitic ores of Northampton came a demand for a grade of coke which the small coal from the Barnsley seam without washing was well calculated to produce. This coke contains more carbon and less ash and other impurities than the Silkstone, and as a result thousands of tons of this fine coal, instead of going into unsightly and useless piles or being used to ballast railways, are utilized in coke-making. Latterly it is stated that the condition of the market for coal has been such that it has been more profitable to make the "run of the mine" into coke, and a large number of ovens, upward of 1,000, were erected in the Barnsley district in 1881. The coke from this coal is competing with that from the Silkstone seam, and even with the Durham. Bee-hive ovens 11 feet in diameter are most common in this district. The coal is generally crushed in a Carr's disintegrator.

The following shows the range of the analyses of the Barnsley coal from six collieries:

	Per cent.
Carbon	80.500 to 82.520
Hydrogen	5.025 to 5.500
Oxygen	6.205 to 8.243
Nitrogen	1.496 to 2.120
Sulphur	1.144 to 2.100
Ash	1.226 to 4.100
Yield of coke	62.000 65.520
Specific gravity	1.266 1.290

The Silkstone seam, so named from the village where it was first worked, also furnishes a coal well adapted for coking. (*a*) Its analysis is as follows:

	Per cent.
Carbon	80.46
Hydrogen	5.08
Nitrogen	1.67
Oxygen	6.80
Sulphur	1.65
Ash	3.30
Moisture	1.04

When coked, the yield is about 60 per cent. The coal from this seam raised at the Hoyland colliery yields 64.48 per cent. of coke. This coal is extensively coked, and produces a pure, strong coke, which is in good demand in the steel works of Sheffield, where it is largely employed.

Of the coke made in the other districts of the United Kingdom our information is of the most meager description, and covers very little else than the fact that it is made.

In Staffordshire some coke is manufactured, though the supplies for South Staffordshire come from Derbyshire.

a See Meade, page 41.

These districts and Yorkshire, with Durham, Lancashire, and South Wales, should be regarded as the chief seats of the coke manufacture of the United Kingdom; but here, as elsewhere, concerning output, ovens, etc., the report must be, "No returns."

In London some coke is made from the screenings of the coal-yards, similar to that made at Cincinnati. There are quite a number of these establishments in London, one having 21 ovens, another 12, another 9, and others various other numbers, and are mostly situated on the river banks.

Regarding coke in Scotland, the only definite information received is that in 1878 there was a bank of 160 ovens at the Haugh works of Messrs. William Baird & Co., in Lanarkshire, which at that time was the most extensive works of the kind in Scotland.

Concerning Ireland, the statement is made that, owing to the great competition with English coke, its manufacture scarcely pays the cost of production and carriage.

During the past few years many attempts have been made to utilize the gases and save the waste products of combustion, especially ammonia and tar, but the success has not in most cases been such as to justify the adoption of the process. The waste heat is used at many places in making steam, and the experiments in collecting the waste products have shown that it can be done. The coke, however, was found to suffer much in quality, so that what was gained in one way was counterbalanced by a loss in another. Some recent experiments are said to have been more successful, so that there is every probability of the valuable products of the gas being obtained without injury to the coke. Messrs. Pease & Partners have recently adopted the Carvés system with excellent results, and other systems are being tried. These will be referred to in another chapter.

As has been stated, there are no reliable statements as to the amount of coke produced in Great Britain. Mr. Richard Meade, to whose work (*The Iron and Coal Industries of the United Kingdom*) I am so much indebted for information, writes me on this subject:

The Newcastle and Durham districts of the Great Northern coal-field are the most important and extensive in Britain. Mr. A. L. Steavenson, a vice-president of the North of England Institute of Mining Engineers, in a paper read before that body and printed in their transactions (vol. viii, 1859-'60) gives the following estimate of the coke trade for the year 1858: Coke used in the iron trade, 4,032,070 tons; coke exported, 227,552 tons; railways, etc., 641,611 tons; total for 1858, 4,901,233 tons. The number of coke ovens employed, about 16,660; and the number of hands employed in the kingdom, about 4,000.

In the same year, in Durham and Northumberland, the production of coke was about 2,000,000 tons, employing 1,600 hands, the capital embarked in the coke trade being about £500,000, yielding about 10 per cent. annually.

In the year 1880 the consumption of Durham coke alone in pig-iron manufacture amounted to 4,500,000 tons, and as the make of pig-iron in the same district has increased since 1880 the coke manufacture will have increased in proportion. There is, however, no information of which I am aware showing the extent of increase that is at all reliable.

As a large number of the iron works in this country manufacture their own coke, it is a very difficult matter to arrive at the production even approximately.

From page 41 of the *Annual Report of the British Iron Trade Association* for 1881 I extract the following:

The production and consumption of coke during 1880 has exceeded all former experience. In Cleveland, Cumberland, and North Lancashire, unitedly, about 4,000,000 tons of pig-iron were made last year, exceeding by nearly a million tons the largest quantity made in any former year. And if an average consumption of 22½ cwt. of coke per ton of iron is assumed, it follows that in the three districts named the quantity of coke used was about 4,500,000 tons, chiefly supplied from the South Durham coal-field. During the last twelve or fifteen months coke has fluctuated very much in value. Commencing in Durham to rise from about 8*s*. per ton in August, 1879, it advanced before the close of the year to 13*s*. 6*d*., and in the early part of 1880 large quantities were sold between the latter figure and 20*s*. per ton. In the latter months of the year, however, prices became easier. (*a*)

a As this report is going through the press a statement, prepared by the secretary of the British Iron Trade Association, is at hand, which contains some interesting information concerning the use of coke in the blast-furnaces of that country in 1882, from which the following is extracted:

"There are no reliable statistics of the production and consumption of coke in the United Kingdom, but the demand for this form of fuel is known to have very largely increased within the last few years. This has chiefly been due to the development of the iron trade, but the demands for locomotive and export purposes have also been extended in a material degree. The economies that have been introduced in blast-furnace practice have, however, so considerably reduced the consumption of fuel per ton of iron smelted that the effect of the greatly increased production of pig has not been so apparent in this industry as it otherwise would have been. The following figures show what the consumption of coke would be in the manufacture of pig-iron in 1882 compared with 1879, assuming for each year an average of 23 hundred-weight of coke per ton of pig:

CONSUMPTION OF COKE IN 1879 AND IN 1882, ALLOWING AN AVERAGE OF 23 HUNDRED-WEIGHT OF COKE PER TON OF PIG-IRON MADE, WITH INCREASE OF CONSUMPTION IN EACH DISTRICT IN THE LATTER YEAR.

District.	CONSUMPTION OF COKE.		Amount of increase in 1882.	District.	CONSUMPTION OF COKE.		Amount of increase in 1882.
	1879.	1882.			1879.	1882.	
	Tons.	*Tons.*	*Tons.*		*Tons.*	*Tons.*	*Tons.*
Cleveland	2,032,448	3,091,947	1,059,499	Lancashire	726,044	900,150	174,106
West Cumberland	611,383	1,151,358	539,975	Northamptonshire	190,114	220,932	30,818
South Wales	770,336	1,015,801	245,465	West and South Yorkshire	251,626	321,141	69,515
North Wales	21,796	56,020	34,224	Derbyshire and Notts	335,173	512,595	177,422
South Staffordshire*	374,647	458,209	83,562	Shropshire	69,908	92,546	22,638
North Staffordshire	241,930	364,684	122,754	Gloucestershire, Wiltshire, etc	46,000	55,200	9,200
Lincolnshire	151,429	231,795	80,366	Total	5,822,834	8,472,378	2,649,544

*In South Staffordshire probably one-half of the fuel used in iron smelting is raw coal, but as the exact proportions are unknown the whole is dealt with as coke.

"These figures show an increase of 2,649,544 tons, or 46 per cent., within four years; but it should be noted that the average consumption per ton of pig is likely to have been higher in 1879 than in 1882, because of the extensive introduction of more economical

The following table shows the exports of coke from Great Britain for 1878, 1879, and 1880, and the value of the same:

Countries to which exported.	1878. Tons, 2,240 pounds.*	1879. Tons, 2,240 pounds.†	1880. Tons, 2,240 pounds.‡	Countries to which exported.	1878. Tons, 2,240 pounds.*	1879. Tons, 2,240 pounds.†	1880. Tons, 2,240 pounds.‡
Russia:				Greece	5,051	17,600	21,556
Northern ports	52,511	48,070	56,309	British India:			
Southern ports	122	250	714	Continental territories	4,400	7,620	6,205
Sweden	18,411	24,140	40,860	Straits settlements	110	200	494
Norway	10,128	10,960	16,028	Ceylon	102	170	229
Denmark	4,902	6,280	6,023	United States of America on the Pacific.	4,851	10,950	16,052
Germany	23,044	32,050	38,761	Chili	5,562	11,290	18,750
Holland	2,363	8,230	8,561	Brazil	2,437	3,100	3,418
France	17,180	14,920	23,038	Other countries	11,114	12,628	17,597
Portugal, Azores, and Madeira	3,872	5,570	3,879				
Spain and Canaries	92,603	106,990	143,218	Total	274,239	345,438	442,797
Italy	15,476	24,420	21,110				

* Value: £201,708. † Value: £231,671. ‡ Value: £338,259.

COKING IN BELGIUM.

The coal-fields of Belgium are among the most important of the continent of Europe, and have given to this little bit of territory an industrial importance and competitive power second only to that of Great Britain. These fields extend across the country from east to west, but vary greatly as to their accessibility, the coal at one place cropping out some 600 feet above the level of the sea, while at Mons it is found some 7,000 feet below the level.

The coal-fields are divided into five districts: Mons, Centre, Charleroy, Namur, and Liége. The first three districts named are included in the province of Hainaut, and statements and reports concerning the coal of this country frequently speak only of the provinces or districts of Hainaut, Namur, and Liége. The province of Namur, however, is of little importance as a coal-producing district, its output being only 3 or 4 per cent. of the product of the country.

The quality of Belgian coal, though, as in most countries, it varies greatly, is on the whole good, the deepest seams being the best and thickest. Nearly half the total production is a close-burning coal, and is used principally for

blast-heating apparatus, and also because of the much larger make of hematite relatively to other qualities of iron in the latter year. The difference, therefore, against 1879 is likely to have been even greater than the foregoing figures indicate. The following table shows the consumption of coke in the manufacture of pig-iron in 1882, both as coke and in the form of coal, Scotland being, of course, excluded, in consequence of the general use of raw coal in the blast-furnaces of that country.

CONSUMPTION OF COKE IN THE PRODUCTION OF PIG-IRON IN THE UNITED KINGDOM IN 1882, THE AVERAGE BEING TAKEN AT 23 HUNDRED-WEIGHT PER TON OF THE IRON MADE.

District.	Consumption of coke.	Equivalent of coal, taking 60 per cent. of coke as 100 per cent. of coal.
Cleveland	3,091,947	5,153,245
West Cumberland	1,151,358	1,918,930
South Wales	1,015,801	1,693,001
North Wales	56,020	93,366
South Staffordshire	458,209	763,681
North Staffordshire	364,684	607,806
Lincolnshire	231,795	386,325
Lancashire	900,150	1,500,250
Northamptonshire	220,932	368,220
West and South Yorkshire	321,141	535,235
Derbyshire and Notts	512,595	854,325
Shropshire	92,546	154,243
Gloucestershire, Wiltshire, etc	55,200	92,000
Total	8,472,378	14,120,627
Add coal consumed in Scotland, say		2,300,000
Total coal		16,420,627

"It is probable that the average yield of the United Kingdom will be nearer 56 to 57 per cent. of coke per 100 of coal, 60 per cent. being indeed about the best average result that is obtained in the coke manufacture. It is probable, also, that the average consumption of coke per ton of pig made will, in the country generally, be nearer 25 than 23 hundred-weight. The foregoing table is therefore subject to these two modifications."

domestic purposes, and to some extent for gas- and coke-making. The production of true coking coal is small, only about 27 per cent. of the entire amount raised. Of this only a portion is coked, less than 17 per cent. of the entire production of coal being made into coke.

The beginning of the manufacture of coke on an extensive scale in Belgium dates from the erection of the first blast-furnace, in 1826, by John Cockerill, at Seraing. In 1830 the number of these furnaces had increased to 5, while there were still 72 charcoal blast-furnaces in existence. Many of these charcoal furnaces were out of blast, however, and coke furnaces gradually took their place until 1865, when there were 56 of them in blast. Notwithstanding this increase, the development of the manufacture of pig-iron in Belgium has not kept pace with the manufacture of coke. The output of iron ores has largely decreased in the last fifteen years, and while their importation has more than doubled in the same period, the production of pig-iron and other uses have not been sufficiently large to consume the coke made, and a large proportion of it has gone to the furnaces of other countries. In 1881 nearly one-half the coke made, or 914,885 out of a production of 1,834,669 metric tons, was exported.

While the production of coke in Belgium has thus been of great moment to the industries of contiguous countries, it has not been wholly the amount that has given the manufacture of coke in Belgium so much importance, but rather the improvements that have been made in coke ovens in that country. Bee-hive ovens were at first used, but as the demand for coke increased it became necessary to adopt better and more economical forms, as well as ovens adapted to coking coals of an inferior character, and the Belgian or flue ovens are the result. These ovens, if they did not originate in Belgium, certainly have received the most attention and reached their best development in this kingdom, and the name Belgian, which has been applied to all flue ovens, is therefore exceedingly appropriate. (*a*)

The official statement as to the number of coke ovens in Belgium and the production of coke in 1881 is as follows:

Localities.	Number of coke ovens.		Number of men employed.	Consumption of coal, net tons (2,000 pounds).	Production in coke, net tons (2,000 pounds).	Value per net ton (2,000 pounds).
	In operation.	Idle.				
First division, Hainaut	2,680	826	1,598	1,972,261	1,441,398	$2 80
Second division, Liége	1,443	608	760	778,334	580,257	
Total	4,123	1,434	2,358	2,750,595	2,021,655	....

While all the ovens in use in Belgium are flue ovens, heated from the bottom and sides, the variety is considerable, but no statement of the number of each kind is given in the official publications. Most of the ovens are horizontal, sometimes with the floor slightly inclined, and are generally placed in single or double lines or banks, but are occasionally clustered (*en ruche*). In some cases the pitch and other products of combustion are saved. The Appolt or vertical oven is also used to some extent, and for some years has been growing in favor, notably at Seraing. (*b*)

There are 57 firms engaged in the manufacture of coke, and the number of each class of ovens built is as follows:

A.—Horizontal, in lines or banks	4,397
B.—Horizontal (*en ruche*)	152
C.—Vertical	1,008
Total	5,557

Two hundred and fifty-nine ovens of class A and 48 of class B are arranged for the saving of the waste products of combustion.

The following tables give in detail the statistics concerning the production of coke in Belgium in 1881:

PROVINCE OF HAINAUT.*

	First district.	Second district.	Third district.	Fourth district.	Fifth district.	Province of Hainaut.
Number of ovens in operation	413	443	1,188	398	238	2,680
Number of ovens idle	77	130	124	228	267	826
Total	490	573	1,312	626	505	3,506
Number of workmen	....	....	....	....	....	1,398
Coal consumed, tons of 2,000 pounds	283,183	251,272	948,398	330,693	158,733	1,972,270
Production of coke, tons of 2,000 pounds	194,601	175,477	702,610	257,940	110,782	1,441,410

* Report of the engineer-in-chief, director of mines of the province of Hainaut.

The average value of the coke was 16.03 francs per 1,000 kilograms, or $2 81 per ton of 2,000 pounds, and the production exceeded that of 1880 by 722,545 net tons.

a This subject is discussed at length in the chapter on "Belgian Ovens".

b This statement is based on a letter from M. Max Goebel, editor of *La Semaine Industrielle*, Liége, to whom I am indebted for many of the facts given concerning Belgian coke.

PROVINCE OF LIÉGE.*

	Seventh district.	Eighth district.	Ninth district.	Tenth district.	Province of Liége.
Number of ovens in operation	246	90	1,023	84	1,443
Number of ovens idle	132	16	404	56	608
Total	378	106	1,427	140	2,051
Number of workmen	150	44	519	47	760
Coal consumed, tons of 2,000 pounds	174,981	54,588	503,743	45,029	778,341
Production of coke, tons of 2,000 pounds	132,057	39,812	373,917	35,177	580,963

*Report of the engineer-in-chief, director of mines of the provinces of Liége and Namur.

The value of the coke was $2 77½ per net ton, and the quantity of coke made in 1880 was 20,025 tons less than in 1879. There are no coke ovens at the mines of the sixth district.

It should be noted that, in addition to the amount given above, a little coke is made in Belgian Luxembourg. The official statistics, however, give no statement of the amount.

From these tables it appears that 2,750,620 net tons of coal were used in the production of 2,022,373 tons of coke, a yield of 73.5 per cent.—much in excess of that attained in the bee-hive ovens in the United States or England. This excess in yield is largely, though not entirely, due to the use of the flue oven. The output per oven was a little over 490 tons for the year.

The production of coke in Belgium for the five years, 1876–'80, by provinces, is as follows:

Year.	Hainaut.	Liége.
	Tons.	*Tons.*
1876	914,415	459,451
1877	899,447	448,169
1878	1,056,401	462,477
1879	1,004,930	480,990
1880	1,270,024	560,938

As has already been stated, a large percentage of the coke produced in Belgium is exported, chiefly to France. Some little coke is imported.

The following table, from the report of the Belgian ministry of finance, shows the imports and exports for the years 1877, 1878, and 1879:

EXPORTS.

Exported to—	1877.	1878.	1879.
	Net tons.	*Net tons.*	*Net tons.*
Prussia	10,163	....	11
Luxembourg	194,918	153,388	119,209
France	322,343	362,021	432,142
Other countries	3,136	3,360	2,832
Total	530,560	518,769	554,194

IMPORTS.

Imported from—	1877.	1878.	1879.
	Net tons.	*Net tons.*	*Net tons.*
Prussia	16,157	13,795	4,410
France	4,290	5,733	5,222
Other countries	176	90	89
Total	20,623	19,618	9,721

The exports of coke have largely increased since 1879, being 937,345 net tons in 1880 and 1,008,487 tons in 1881.

The apparent anomaly presented by the above tables of the importation into Belgium of coke from Prussia, and even a small quantity from France, to which Belgium sends so much coke, is explained by the location of the works using it relative to lines of transportation, they being of easier and cheaper access to the French and Prussian coke manufactories than to the Belgian.

COKING IN FRANCE.

The French coals, even of the coking variety, are, as a rule, not well adapted to the manufacture of coke, being, as compared with the English and the Belgian coals and those of Westphalia, very impure and high in ash, the amount being such that the fuel would hardly be used at English or American blast-furnaces. By carefully washing the coal and by proper attention to coking, however, the difficulty is reduced to a minimum. The results obtained in French iron works with their fuel is most creditable to their management.

There are in France six principal coal-producing districts. (*a*)

1. *The northern coal-field.*—This district extends over a part of the departments of the Nord and Pas-de-Calais, from the Belgian frontier up to and beyond the city of Bethune, and more particularly in the environs of Valenciennes and Douai. The coal-measures comprise a rather large number of seams, generally varying in size from 0.50 to 1 meter. (*b*) Various kinds of coal are produced, including anthracitic, semi-bituminous, and coals suitable for making coke. These coals vary also as regards the percentage of ash, and a like observation applies to the coke produced. Two kinds of coke are made in the department of the Nord, viz: the washed coke, containing from 7 to 8 per cent. of ash, and the unwashed, containing from 12 to 14 per cent., and sometimes more. This coal-field has the advantage of possessing a great number of railways and canals in connection with the Seine, Marne, and Meuse, so that its products are conveyed a considerable distance.

2. *The Burgundy coal-field.*—This district occupies a portion of the department of the Saône and Loire between Autun and Charolles, its principal collieries being those of Blanzy, Epinac, and Creusot. There are but few seams, and those of somewhat varied characteristics, the thickness being not unfrequently considerable, while the seams are worked by means of shafts sunk to a depth of 250 or 300 meters, or more. At Creusot the coal is nearly an anthracite, but it undergoes a change eastward, where it becomes very flaming, and, to a certain extent, is adapted to coke, without, however, being really a coking coal. The small coals have to be washed in order to produce coke with even as little as 12 per cent. ash. The Creusot coal is not suitable for carbonization, except when mixed with a considerable proportion of coking coal of the Saint-Étienne district.

3. *The central coal-field.*—This is situated in the department of the Allier, and the principal collieries are those near the town of Commentry and the village of Bezenet. A fine seam, with but little incline and an average thickness of, say, 14 meters at the former place and a somewhat irregularly formed seam at the latter, is worked. The coal is flaming and gaseous, and yields a rather light kind of coke, which, when produced from washed coal, contains from 10 to 12 per cent. of ash. To this main coal district may be attached some small outlying coal-basins, one of which is the Saint-Eloy basin, in the neighboring department of the Puy-de-Dôme, supplying coal and coke, with a good proportion of ash.

4. *The Loire coal-field.*—Next to the coal district of the Nord the Loire district is the most important, more especially in the vicinity of Saint-Étienne and Rive-de-Gier. It comprises a number of seams of no inconsiderable extent, the total accumulated thickness of which is calculated at from 50 to 70 meters, the whole depth of the coal-measures being about 1,800 meters. The proportion of ash in the coke obtained from the small washed coal is generally from 12 to 13 per cent.

5. *The Aveyron coal-field.*—This district is situated in the department of the same name, and the chief collieries are those of Decazeville and Aubin. The seams are nearly horizontal, and are of but little depth. The coal here has to be carefully washed in order to obtain such a kind of coke as would be suitable for use in blast-furnaces. This coke, which is not very dense, generally contains from 10 to 12 per cent. ash.

6. *The Alais coal-field.*—This ranks as the third important coal district in France, and is situated in the department of the Gard. The seams differ in thickness (from 0.30 to 2 meters), and yield sundry kinds of coal, varying from the anthracite to the flaming sort, including the intermediate coking and bituminous qualities suitable for coke. Coke of good quality and with but little sulphur is made from the washed small coals, with from 10 to 14 per cent. ash in the kinds suitable for blast-furnaces.

As regards the center of France, mention may be made of the Brassac basin in the Haute-Loire (which sends its coking coal as far as Creusot), and the Ahun basin, department of the Creuse, also producing coking coal and supplying two or three smelting works in the neighborhood.

In the east the Ronchamp coal formation, situate on the southern slope of the Vosges, department of the Haute-Saône, furnishes a certain quantity of fuel to the Franche-Comté iron works.

In the southwest the Carmaux basin (department of the Tarn) supplies coke to some iron works, particularly those near the Pyrenees, and the Graissesac basin (Herault) produces also coal fit for coke.

Generally speaking, coke is no longer manufactured in France except in the Belgian ovens, chiefly of the Smet, Coppée, or Appolt systems. The Smet and the Coppée ovens are principally used in the Anzin, Commentry, Saint-Étienne, Aveyron, and Grand-Combe collieries; the Appolt at Blanzy, Creusot, Bezenet, Portes, and other places. A number of ovens on the Carvès system, for utilizing the waste products, are in use with good results, especially

a Condensed from a paper by Professor S. Jordan, of Paris, read before the British Iron and Steel Institute, at its Paris meeting, 1878.
b The meter is 39.370 inches.

at Saint-Étienne and Terrenoire. Almost all the small coal used is washed, as with few exceptions French coal would not be otherwise pure enough to produce a sufficiently clean coke for manufacturing purposes.

It is very difficult to arrive at the yield of the French coal in coke. In the Saint-Étienne coal-field at one point there are 122 Belgian ovens, using crushed and washed coal, 175 tons of coke being made per day. The charge is from 4 to $4\frac{1}{2}$ tons, and it is burned 48 hours, yielding about 3 tons, or 72 per cent. The average ash in the coal is $13\frac{1}{3}$ per cent., but by double washing it is reduced to from $4\frac{1}{2}$ to 8 per cent. At Saint-Étienne 80,000 tons of coal are burned per year, producing as follows:

	Tons.
Large coke	52,008
Small coke	3,500
Graphite	30
	55,538

or 69.4 per cent. of coke, beside 2,400 tons of tar and 300 tons of ammonia product. The best information is to the effect that the average yield of coal in coke in France is 70 per cent.

The price of coke in 1878 varied from 20 to 27 francs ($3 86 to $5 21) per ton at the ovens, according to the purity of the article and the situation of the coal-fields.

In addition to the fuel from French collieries, the French metallurgical works import coal and coke from foreign countries, as, for example, from England (the cargoes being discharged at the channel and ocean ports), as well as from Belgium, and, via the Belgian frontiers, Westphalia. It would even be possible to quote an establishment in the southwest of France which receives its coke, via Rotterdam and Bordeaux, from the Ruhr carboniferous district (Essen, in Westphalia).

Considerable coke is brought into France from other countries, and some small amounts are exported, the imports and exports for 1881 by countries, and for 1879 and 1880 by totals, being as follows:

Countries.	Imports.	Exports.
	*Tons.**	*Tons.*
Belgium	902,771	
Germany	190,487	
Switzerland		7,275
Italy		7,585
Other countries	17,796	9,754
Total 1881	1,111,054	24,614
Total 1880	943,416	40,905
Total 1879	760,529	20,589

* This ton is probably the metric ton of 2,205 pounds.

The official publications of the French government contain no returns of the annual production of coke. Pechar estimates it at 1,400,000 metric tons (1,543,234 tons of 2,000 pounds), requiring about 2,000,000 metric tons (2,204,620 tons of 2,000 pounds) of coal. This would indicate the same yield as is stated above, 70 per cent. Adding to this the imports and subtracting the exports, it would leave for consumption in France, in 1880, 2,302,511 metric tons, or 2,538,081 tons of 2,000 pounds.

COKING IN GERMANY.

The introduction of the steam-engine into the mines and iron works of Germany in 1784 gave, as it did in other countries, a strong impetus to the development of its coal and iron industries, as also to the production of coke. The first coke blast-furnace was erected at Gleiwitz, in Upper Silesia, in 1796. This was followed by the introduction of coke-furnaces in Königshütte in 1802, in Hohenlohhütte, which was the first private works, in 1805, and in the district of the Saar in 1848.

The chief coke-producing region of Germany, as well as the source of nearly half its coal, is Westphalia. The coal-basin of this district, which is also called, after the river which runs through its southern part, the basin of the Ruhr, is about 70 kilometers in length and 20 kilometers in breadth (say 43.5 miles in length and 12.43 miles in breadth). In this space of about 650 square miles are raised more than 20,000,000 tons of coal annually—55 per cent. of all produced in Prussia, and about 49 per cent. of all produced in the German empire. (*a*) There have been developed 74 workable seams of over 20 inches each, the total thickness of coal being 70 meters, or $229\frac{3}{4}$ feet. The coking coal belongs to the third group of seams, and includes 23 seams. Nearly all the collieries possess apparatus for separating and washing their coals.

a The meeting of the British Iron and Steel Institute at Düsseldorf in 1880 was the occasion of the presentation of a series of papers on the coal and iron industries of Germany. It is from Dr. Gustav Natorp's paper on the "Coal Industry of the Lower Rhine and Westphalia" that most of the facts in this chapter are derived.

The percentage of ash, which varies in the coal between 10 and 15 per cent., is reduced by preparation to an average of from 4 to 5 per cent., even in the least clean descriptions, such as nuts and dust coal.

While the larger descriptions of the prepared product are used for domestic fuel and boiler and other industrial purposes, the dust coal, as well as the greater part of the smallest class of nuts, which are crushed for the purpose in disintegrators and mixed with the dust coal, are used for the fabrication of coke, and when manufactured from this mixture contains on an average from 6 to 7 per cent. of ash.

For the manufacture of coke out of Westphalian coal there existed early in 1880 about 2,400 coke ovens at the collieries, 1,700 at the iron works, 1,200 in private hands; in all, 5,300. This number increased in 1880 about 500. By far the greater number of these ovens is constructed on the so-called Coppée system, which has, however, in late years undergone some improvements in the brick-work and in the volume of the oven. There are only 500 coke ovens on an entirely different system, approaching the English bee-hive in shape. While the Coppée ovens, and especially those of improved construction, coke from 6 to 7 tons of coal in 48 hours, with a production of 70 per cent., the bee-hive ovens hold only 5 tons of coal, require 72 hours to coke the same, and produce from 54 to 60 per cent. of coke.

Although it is the opinion of some iron engineers that the coke produced in the bee-hive ovens is superior in many respects to that of the Coppée ovens, the former have, nevertheless, not been generally adopted, since a coke can be far more cheaply produced in the Coppée ovens, which answer all the requirements, not alone of our own native iron industry, but that of Belgium, Luxembourg, and France. (*a*)

The approximate number of ovens, quantity of Westphalian coal used for coking, and of the coke manufactured, is shown by the following table:

Coking works.	Number of coke ovens.	Coal used.	Coke produced.
		Tons.	*Tons.*
1. Collieries	2,400	1,530,000	1,020,000
2. Iron works	1,700	1,057,500	750,000
3. Private works	1,200	765,000	510,000
In all	5,300	3,352,500	2,280,000
Per year and oven		633	430

Through the kindness of Dr. Hermann Wedding I am enabled to give the following statement regarding the production of coke in Prussia. These statistics are not gathered officially, either as to the amount produced or as to the number of coke ovens, but the following figures, derived from sources not official, may be considered very nearly correct:

	Tons.
District of Upper Silesia	434,199
District of Lower Silesia	127,596
District of Lower Westphalia (Ruhr district)	2,280,000
District of the Saar	510,103
District of Aix-la-Chapelle	13,259
District of Oberkirchen	32,096
Total	3,397,253

In Upper Silesia the coal is somewhat inferior in character, and as a rule does not coke. However, some coking coal exists at Zabize, and from the slack from the mines at this place some coke is made in bee-hive and Belgian ovens. From the non-coking or poor-coking coals of the eastern district of Königshütte, etc., coke, as a rule, is produced either in heaps or in open kilns. Large bee-hive ovens or closed kilns are used to a still less extent, and recently some Belgian ovens have been introduced, the coke made being for furnace use. The number of ovens or heaps is not known.

Lower Silesia contains some good coking coal, which is coked in Belgian ovens, generally on the Coppée system, and is mostly for foundery purposes. A statement regarding the coking coals of Rhenish Westphalia is given above.

In the Saar district there are some good deposits of coking coal, but the coke made is not as good as that of Westphalia. Belgian as well as some Appolt ovens are used, as in Silesia.

In Aix-la-Chappelle the deposits of coking coal are extensive. There are 257 Belgian ovens in use, with some ovens on the system Lürmann for poor coal. The cokes made in this district are for blast-furnace purposes.

In Oberkirchen, where the coal is very pitchy, light, porous coke is made in open kilns, and is used mostly for lead and copper smelting.

The designation of ovens in Germany is so peculiar as to demand a word of explanation. The terms used are open ovens, closed ovens, narrow ovens, and Appolt. The open oven is what we have termed the open kiln, the closed oven either the bee-hive or its modification, the rectangular oven, without flues, the narrow oven the horizontal Belgian oven, and the Appolt oven the vertical Belgian.

a See Dr. Natorp's paper.

Nearly all iron works in the neighborhood of coal-mines have their own coke ovens and use the escaping gas to heat the boilers, but the greater part of the iron works situated at some distance from the mines purchase coke, while some is brought from Belgium.

The total output of the coke works of Germany in 1878 is given in the *Colliery Guardian* at 5,403,392 tons. Prices have fluctuated considerably recently. At the beginning of 1879 furnace coke was quoted at 22*s.* a ton, a decline, as compared with 1878, of 16 per cent. In May, 1879, Silesian and Westphalian coke were quoted at Berlin at from 19*s.* to 20*s.* per ton. As showing the cost of freight, these same cokes were quoted at the ovens at from 7*s.* 6*d.* to 8*s.* 6*d.* In January, 1880, coke at Dortmund was quoted at 26*s.*; in February, at the same place, 28*s.*; in April, at the pit, £1 8*s.* 3*d.*, and in May, 1880, Westphalian coke at Hamburg was 50*s.* About this time speculation lost its power, and coke sold at the close of 1880 at from 9*s.* to 10*s.* per ton at the pits.

COKING IN AUSTRIA-HUNGARY.

Though some portions of Austria-Hungary are among the oldest iron-producing districts of the world, the small supply of coal of a coking character, and its distance from the best deposits of iron ore, have seriously interfered with the development of its iron resources, and consequently with the use of coke. The distribution of these two minerals is also such that the best ores and the good coking coal are not together. In the Austrian alpine countries, Styria and Carinthia, which are very rich in excellent iron ores, charcoal is at present almost the exclusive fuel used for making pig-iron. This section has no coking coal, and the long distances and high railway tariffs admit only of a limited use of coke from other sections and countries. In Bohemia, Moravia, and Silesia there are large deposits of good coking coal, but the ores are inferior to those of Styria and Carinthia. It was not until 1838 that pig-iron was made with coke in this district, the first blast-furnace, which was also the first in Austria, having been erected at Witkowitz in this year; but since the year 1870 its use has become more general, and at present one-half of the production of pig-iron is with coke.

It is in these provinces of Austria that nearly all the coke made in Austria-Hungary is produced, the chief centers of production being Kladno and Pilsen in Bohemia and Ostrau-Karwin in Silesia. The coke from the latter district is an excellent furnace fuel. That from Kladno is used at the works of the Prague Iron Company, the most extensive coke blast-furnaces in the empire. The average yield of the coal of the Ostrau-Karwin district in coke is estimated at from 55 to 61 per cent. About 8 per cent. of the output of the district is coked. At present the production is limited by the high cost of transportation to the iron works.

The manufacture of pig-iron in Hungary has advanced much in the course of the last few years, but a scarcity of suitable coking coal also prevails here. Of the 68 blast-furnaces of Hungary but one uses coke entirely, and one other part charcoal and part coke. Only small quantities of Banatian coal are made into coke, but this is excellent, and the yield is the highest in the empire. For the other operations of iron and steel making most of the fuel used is brown coal or lignite, of which Austria-Hungary possesses rich deposits of a most excellent character. There are, however, some deposits of coal of a coking quality well adapted for use in furnaces, and, though inconveniently situated in respect to the ore deposits, those metallurgists who know the country best are sanguine as to its availability in the near future. While some quite successful experiments have been made in producing coke from lignite, the amount made is quite small.

The statistics of coke-making in this empire are very meager. The following quantities of coal were, according to Pechar, used for coke in the year 1876:

	Metric tons.
In the Ostrau district	126, 419
In the Kladno district	71, 973
In the Pilsen district	43, 281
In the Schatzlar-Schwadonitz district	7, 340
In the Rossitz district	7, 129
In Hungary	2, 974
Total	259, 116

Assuming the yield to be 58 per cent., this would make a total production of about 150,287 metric tons. From another source the following statement of the make of coke in Austria in 1878 is given:

	Metric centners.
Bohemia	1, 192, 566
Moravia	574, 026
Silesia	1, 073, 445
Total	2, 843, 037

or 175,503 net tons, a result that does not differ much from the production estimated above. A portion of this, some 13,400 metric centners, was exported in 1878 to Prussia and Russia.

The same causes that result in a high price of coke and fluctuations in the price in other countries rule in Austria, though the high price is more largely due to the heavy cost of railway carriage. In 1879 coke cost, delivered at Loeben, 17 florins 40 kreutzers, or, at 48 cents the florin, $8 48 per ton, and at Bordenberg 16 florins, or $7 68.

COKING IN OTHER EUROPEAN COUNTRIES.

But little coke is manufactured in continental Europe outside of the countries already named, viz, Belgium, France, Germany, and Austria-Hungary. In the other states the coal is either non-coking or is so situated with reference to transportation, ores, and centers of demand that it is more economical to use other fuel. In Norway no coal is mined; in Sweden the only coal worked is in the Lias, and is non-coking. There are a few coke ovens, less than ten, at Stockholm, which make coke from English coal and its slack, for use in small passenger river steamers. As no coke is used in the Swedish blast-furnaces, the demand is very small, and, with the exception noted, is supplied from England. Denmark proper has no coal-beds. There are two small mines in the island of Bornholm, a dependency of Denmark, but the whole output is used on the island, chiefly in the manufacture of brick. Lignite is also found in Iceland, but no coke is made from it. Russia has very extensive deposits of coal, some of which is well adapted to coking, but the immense forests of this empire furnish such boundless supplies of charcoal that most of the iron is smelted with this fuel. The means of transportation are also so inadequate and expensive that it is cheaper to purchase iron abroad, and as a result, the demand for coke is light, and but little is made. The Donetz coal, which is coked to some extent, yields from 51.75 to 81.99 per cent. in coke. In Holland coal is found only in the province of Limburg; but the output is insignificant, and no coke is produced. Coal is found in many places in Turkey and Greece, but very little of it is mined and no coke is made, though some of it is of a coking character, and many deposits of iron ore exist. The coal deposits of Italy are mostly lignite, and of Switzerland anthracite and lignite, little or no coking coal being found. In Portugal there are but two coal-fields worth mentioning, and no coke is made.

But little is known of the production of minerals in Spain, with the exception of iron ore, and that little not of recent date. The Spanish coal-basins are of considerable importance, furnishing some coal adapted to coking, and, on the whole, are well situated with respect to outlet, the deposits of iron ore being among the most extensive, richest, and purest in the world. Notwithstanding these natural advantages, however, Spain imports fully half the coal she uses, and exports nearly all the iron ore, instead of working it into the various forms of cast and manufactured iron. Some pig-iron is made in Spain with coke, chiefly imported, however, but the fuel generally used is charcoal. Probably the main obstacle in the way of the development of its coal, and, consequently, of its coke industries, is the lack of transportation in the interior of the country. In 1872, in the province of Cordova, 5,717 metric tons of coke were produced; in 1871, 4,707 metric tons; and in 1870, 2,589 metric tons; but as the estimated annual consumption of coal in the iron and metal industries of Spain is 500,000 metric tons, this is probably below the actual make.

At the close of 1882 there were in Spain five coke works. At one of these, that of Sociedad Anónima, at Mieres Asturias, three methods of coking were used.

First: A bank (macizo) of 40 furnaces, Smet system (Belgian), with a capacity of 3,000 kilograms each of washed coal. The burning lasts 40 hours, and a yield of 60 per cent. is obtained.

Second: A bank of 30 ovens, similar to the Coppée, but modified by the society. Each oven holds 3,000 kilograms of coal, and yields 63 per cent. in 30 hours.

Third: Beside this, some 7,000 or 8,000 tons of coke are produced annually in heaps in the open air with the same class of coals, but in this system the yield does not exceed 48 per cent.

PART IV.—COAL, COAL-WASHING, ETC.

COKING AND NON-COKING COALS.

Certain kinds of bituminous coal when heated to a temperature varying somewhat with their character swell, become pasty and sticky, and throw off bubbles or jets of gas, which burn with a bright flame as they escape into the air. When lumps or particles of these varieties of coal are thus heated to the pasty condition they lose all traces of their original form, appearance, and structure, and unite into a coherent mass, or, in technical language, are said to "coke" or "cake", and the coal which thus cokes or cakes is termed a "coking" or "caking" coal. (*a*) On the other hand, a non-coking coal (*b*) is one that, under similar treatment, either coheres feebly or not at all, the forms of the original particles or lumps being clearly distinguishable. The solid product or the carbonaceous residue of the burning or heating of both the coking and non-coking coals is termed "coke", though in the arts this word is generally applied only to that coke which is made from true coking coal, or from admixtures of non-coking coal in proper proportions with coking coal or pitch, by which a firm coherent coke can be produced.

It is important to distinguish clearly between what may be termed "industrial coke" and "crucible" or "laboratory coke". The latter is the coke produced in a small way in the laboratory of the analyst, and includes not only the carbonaceous residue obtained in the analysis of coal, but that from pitchy and other carbonaceous substances as well. "Industrial coke" includes only the firm coherent cokes made from coal on a large scale for use in the manufacturing or industrial arts. The percentage of carbon and other elements in "industrial coke" and "laboratory coke" from the same coal will differ very materially, owing to the difference in the methods of manufacture and the greater care exercised in the production of the latter. It is important, therefore, in making comparisons of the analyses of different cokes and the yield of coal in coke, to know that the cokes were made in a similar manner, industrial coke being compared with industrial coke and laboratory coke with laboratory coke. Any comparisons of the analyses of industrial with those of laboratory cokes will be misleading unless due consideration is given to the fact that they are not made in the same way, and unless the necessary deductions are made. Much costly disappointment has arisen from a failure to make this distinction.

Industrial coke can be broadly divided into two classes: "oven coke," or that made in ovens, pits, or mounds, and which is a direct product, the manufacture of coke directly being the object of the carbonization of coal; and "gas coke", or the solid carbonaceous residue of the process of manufacturing gas. In this report I deal chiefly with that termed "oven coke", and unless otherwise specially noted the word coke will be synonymous with "oven coke".

Coke is not the result of simple fusion, the temperature necessary to produce it being above that at which the coal suffers decomposition. In the process the volatile bodies are driven off and a portion of the non-volatile compounds are decomposed, their carbon becoming to a great extent fixed, their hydrogen and oxygen being dispersed. The earthy and non-volatile substances of coal and those not decomposed by heat are nearly all found in coke.

The coking power of different coals differs greatly, and the quality of the coke made under different conditions and in different ovens from the same coal will show marked differences of character as well as of economic efficiency. A coal that in its natural state will make a very poor coke will, when crushed and washed, sometimes give very good results. (*c*) Some coals that are practically non-coking when treated in the usual way, will, when rapidly exposed to a high temperature, give a fairly solid, hard coke. (*d*) It is therefore evident that something beside analysis or a trial in a single oven is necessary to determine whether or not a given coal is adapted to the making of coke. Analysis will give some indication of this fact, and the character of the laboratory coke obtained from the coal still further indications; but the most satisfactory evidence of the value of a coal for making coke is given by a practical trial in ovens or pits, and even then, in case of failure, it is not fully settled but that in different ovens, under different conditions of preparation and coking, different results might not be obtained.

These uncertain relations between coal and the character of its coke have led to many investigations, having for their object the determination of the element or elements upon which its coking properties depend. In a general way, it can be said that as a coal approaches the vegetable on the one hand and the anthracite on the other it loses its coking qualities; but so far investigation has failed to show which is the element or elements the presence or absence of which in a greater or less degree determine its value in coke-making, or has failed to show, if it is not so determined, upon what the coking power of a coal depends. It certainly is not the carbon, nor is it the amount of volatile matter, for the non-coking coals contain these in the largest amount. With this uncertainty as to what is the element on which coking depends, analysis would of course fail to show the value of a coal for

a The terms "caking" and "cake" are used much less frequently in this country than in Europe.
b "Free-burning" and "non-coking" are synonymous terms, as are "binding" and "coking".
c See *Second Geological Survey of Pennsylvania*, Report KKK, page 200.
d See Percy's *Metallurgy: Fuel*, page 309.

the manufacture of coke. Indeed, Professor Stein, of the polytechnic school of Dresden, has shown that coals having the same ultimate analysis may in the one case be coking and in another non-coking. (*a*) The same has been noticed of American coals. Mr. J. J. Stevenson, of the geological survey of Pennsylvania, notes that the coal of the Conemaugh is apparently the same as that obtained on the Youghiogheny. The coke of the latter is compact, silvery, and retains its luster for an indefinite period, whereas that from the Conemaugh is comparatively tender, dull-looking, and on exposure soon loses its little luster. (*b*) Mr. John Fulton, mining engineer of the Cambria Iron Company, gives the opinion that "ordinary analyses fail to indicate the essential qualities of a good coking coal". It has sometimes been claimed that it is the amount of hydrogen and oxygen, or the relation of the amount of oxygen to the carbon, that determines the coking qualities of coal; but both Percy and Fulton refuse to accept this, and suggest that the coking properties of a coal depend, not on the elements or their proportion, but rather on the presence of different kinds of bitumen, or, in other words, on the manner in which the elements other than the ash are combined; that is, on the proximate, not the ultimate, analysis. Considering the difficulty of reaching the true proximate analysis, it will still hold true that the only sure way of determining the adaptability of a coal to the manufacture of industrial coke is to try it and study the result.

It also appears that, in addition to this uncertainty as to the coking value of coals, judged by their analysis, there are other conditions that materially affect this property. For example, some coals speedily lose their power of coking after leaving the pit: in some cases after the expiration of one or two days; in others, after having been exposed to the weather for some weeks or months. In other cases, coals from pits in which fire-damp occurs lose their coking powers on exposure to a certain temperature (300° C.). It has also been noted that while the presence of a large amount of inorganic matter, or what would be the ash, in the coke diminishes, and beyond certain limits destroys, its coking qualities, yet examples are not wanting in which a coke with as much as 21 or 22 per cent. of ash has retained its coking property.

The following analyses, in addition to those found in other parts of this report, will show the composition of the coking coals of Great Britain and the continent of Europe that are used in the manufacture of industrial coke. When not otherwise stated, the yield and composition of the coke given is of laboratory coke:

BRITISH COKING COALS.*

Number.	Localities.	Specific gravity.	Composition, exclusive of water only.†						Water.	Coke.	Composition, exclusive of nitrogen, sulphur, ash, and water.		
			Carbon.	Hydrogen.	Oxygen.	Nitrogen. (‡)	Sulphur.	Ash.			Carbon.	Hydrogen.	Oxygen.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	Northumberland	....	78.65	4.65	13.66	....	0.55	2.49	....	....	80.67	4.76	§ 14.57
2	......do	....	82.42	4.82	11.11	....	0.86	0.79	....	....	83.09	4.85	§ 12.06
3	......do	1.276	81.41	5.83	7.90	2.05	0.74	2.07	1.35	66.70	85.58	6.12	8.30
4	......do	1.259	78.69	6.00	10.07	2.37	1.51	1.36	....	....	83.05	6.33	10.62
5	Nottinghamshire	....	77.40	4.96	7.77	1.55	0.92	3.90	3.50	63.18	85.88	5.50	8.62
6	Blaina, South Wales	....	82.56	5.36	8.22	1.65	0.75	1.46	....	....	85.88	5.57	8.55
7	......do	....	83.44	5.71	5.93	1.66	0.81	2.45	....	....	87.77	6.00	6.23
8	......do	....	83.00	6.18	4.58	1.49	0.75	4.00	....	....	88.53	6.59	4.88

* Percy's *Metallurgy: Fuel*, pages 322 and 323.
† The water is included in the case of No. 5.
‡ The nitrogen, when not quantitatively determined, is included in the number indicating oxygen.
§ Includes nitrogen and sulphur.

COKING COALS OF THE CONTINENT OF EUROPE.

Number.	Localities.	Specific gravity.	Composition, exclusive of water.						Water.	Coke.	Composition, exclusive of sulphur,* ash, and water.		
			Carbon.	Hydrogen.	Oxygen.	Nitrogen. †	Sulphur.	Ash.			Carbon.	Hydrogen.	Oxygen and nitrogen.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
9	Épinac	1.353	81.12	5.10	11.25	....	....	2.53	....	63.60	83.22	5.23	11.55
10	Alais, department du Gard	1.322	89.27	4.85	4.47	....	....	1.41	....	78.00	90.55	4.92	4.53
11	Rive-de-Gier	1.298	87.45	5.14	3.93	1.70	....	1.78	....	68.00	89.04	5.23	5.73
12	.....do	1.288	82.04	5.27	9.12	....	....	3.57	....	72.00	85.08	5.46	9.46
13	Céral, department de l'Aveyron	1.294	75.38	4.74	9.02	....	....	10.86	....	58.40	84.56	5.32	10.12
14	Saint-Girons	1.316	72.94	5.45	17.53	....	....	4.08	....	44.80	76.05	5.69	18.26
15	Mons	....	85.10	5.49	7.25	....	....	2.16	....	72.90	86.98	5.61	7.41
16	.....do	....	80.55	5.53	9.52	....	....	4.40	....	69.15	84.26	5.78	9.96
17	.....do	....	86.38	4.48	6.09	....	....	3.05	....	80.58	89.10	4.62	6.28
18	Charleroi	....	86.47	4.68	5.30	....	....	3.55	....	84.43	89.65	4.85	5.50
19	Valenciennes	....	84.84	5.53	6.83	....	....	2.80	....	67.75	87.28	5.69	7.03
20	Pas-de-Calais	....	86.78	4.98	5.84	....	....	2.40	....	77.05	88.91	5.10	5.99
21	Hungary	1.295	86.93	4.35	6.47	....	0.86	0.89	1.20	78.85	88.72	4.66	6.62
22	.....do	1.300	86.95	4.13	6.76	....	0.99	2.85	1.14	83.14	88.85	4.23	6.92
23	.....do	1.313	80.67	4.38	6.30	....	2.83	5.82	1.04	82.82	88.30	4.80	6.90
24	.....do	1.378	69.50	4.12	9.35	....	5.53	11.41	1.57	77.81	83.76	4.97	11.27
25	.....do	1.350	79.63	4.46	4.68	....	0.90	10.33	1.08	81.55	89.69	5.03	5.28

* Except when the sulphur is not separately stated.
† The nitrogen, when not quantitatively determined, is included in the number indicating oxygen.

a See Percy's *Metallurgy: Fuel* (London, 1875), page 308.
b Report KKK, pages 199 and 200, *Second Geological Survey of Pennsylvania.*

As has already been indicated, neither the composition of a coal nor the analysis of the coke made from it in the laboratory is an unfailing evidence of its value as a coking coal or of the character of coke it will make. The quality and some of the properties of coke depend, not only upon the composition and character of the coal from which it is made, but also upon the manner in which the coking process is conducted, upon the oven used, and in some cases upon the previous preparation of the coal. In view of this, it is especially true that the only way to judge properly as to the value of a coking coal is first to study the character of the coal to be coked and endeavor to adopt the plan best suited to its character, and then try the plan and study the coke.

It should also be borne in mind that the yield of coke, as shown by analysis in the laboratory, is generally in excess of the actual yield in the oven. The laboratory coke made from Connellsville coal in one of the analyses given is 68.633 per cent., but the actual yield in the bee-hive ovens in the Connellsville region, as shown by the reports to the special agent, is from 62 to 67 per cent., averaging about 64 per cent. Some samples of the Miller coal at Bennington, Pennsylvania, yield theoretically, or in the laboratory, 77.25 per cent., but the actual yield, when coked in open pits, was 59.10 per cent. This discrepancy between the theoretical and the actual yield is due largely to a partial consumption of the carbon of the coal in the process of coking. For example, in coke made from Connellsville coal, in which the amount of carbon in the coal used was 59.62 per cent., which amount should have been found in the coke if none had been burned, the actual carbon was but 54.25 per cent., the ash and the sulphur being the same in both the laboratory and the industrial coke; in other words, but 91 per cent. of carbon was found in the coke. In the Miller coal at Bennington, above referred to, the carbon found by analysis was 68.50 per cent., whereas the actual amount found in the coke was only 50.35 per cent., or but 73½ per cent. of the amount of carbon actually in the coal. It would therefore follow that by those methods of coking in which the air is the more perfectly excluded from the oven less of the carbon of the coal would be consumed in the process of coking, and consequently the yield of the coal in coke would be greater. This is borne out in actual experience. As, for example, the Miller coal above referred to, when coked in open pits, yielded 50.33 in a possible 68.50 per cent. of fixed carbon, or 73.5 per cent., whereas the same coal coked in a Belgian oven yielded 61.25 in a possible 68.50 per cent. of fixed carbon, or 89.4 per cent. of the amount of carbon in the coal, showing a loss of but 10.6 per cent. of the fixed carbon when coked in the Belgian oven, as compared with 26.5 per cent. when coked in open pits. These facts show again the necessity of not depending fully on analyses, and also the importance of having careful practical trials made before deciding on the manufacture of coke.

PROPERTIES AND COMPOSITION OF COKE.

Industrial cokes differ greatly in their external appearance, their physical character, and their chemical constitution. In external appearance coke may be light gray and bright, or, as it is generally termed, "silvery" or of "metallic luster", or it may be dull and black. Occasionally it is iridescent. It is generally rough surfaced, but sometimes, especially that portion of a charge near the walls of the oven, it is smooth and glassy, having the appearance of polished graphite. Sometimes also hair-like threads are observed on masses of ordinary coke.

In its physical structure it may be porous and light, or compact, dense, and heavy; hard and capable of sustaining a high crushing and compressive strain or load, or soft and brittle, with a low crushing point and compressive strength. Its "ring" or sound, when struck, is in some samples almost metallic, and in others dull and heavy. Its degree of combustibility, as well as its ease of ignition, also varies.

The terms "dense" and "hard" as applied to coke have a special meaning that should be carefully noted. All coke is more or less cellular in its structure. The less the cell space the denser the coke; the greater the cell space the more porous; that is, "dense" and "porous" are opposite conditions. Hard is a term properly applied to the cell walls of the coke, and not to the cell space, and coke is hard or soft as the cell walls are hard or soft. Coke may, therefore, be very dense and not hard; that is, its cell space may be small and the walls of the cells weak, or it may be porous and hard, or its cell space may be large and the walls hard and strong. Physically, the typical coke for blast-furnace use should be bright silvery, hard and porous, with a metallic ring, and some of these conditions of physical structure are of more importance in determining its value than has been generally apprehended, and are deserving of more careful consideration than has usually been given them. It is no doubt important that the amount of certain of the chemical constituents of coke should be as high, and of others as low, as possible; but it is equally true that for certain purposes, for iron-smelting for example, unless certain physical conditions exist, the coke is comparatively useless. The content of carbon may be the highest and of ash and sulphur and volatile matter the lowest; but if the coke is soft and brittle its value as a furnace fuel is very small. A dense coke, or one with a small amount of cell space, other things being equal, is within certain limits inferior to one that is porous or with considerable cell space; while a hard coke, or one in which the walls of the cells are hard and strong, is superior to one in which the cell walls are brittle and weak. The importance and bearing of these physical properties of coke will be treated of in later pages.

In its chemical composition coke is essentially carbon and ash, which is the fixed, inorganic matter of the coal from which it is derived. It contains also hydrogen, oxygen, nitrogen, phosphorus, and sulphur, and, in the coke of commerce, more or less water. All of these constituents, with the exception of the carbon, are impurities, and the value of cokes of the same physical structure is inversely as the amount of these impurities.

In an analyses of coke the impurities are usually grouped under the general terms ash, volatile matter, sulphur, and in some cases other impurities are given separate from the ash. Ash is the unburnt and unvolatilized residue of the complete carbonization of coal or coke. Its chief constituent is silica, with considerable alumina and sesquioxide of iron. In the description of the Connellsville region of Pennsylvania an analysis of coke by Mr. E. C. Pechin is given, in which there is 9.523 per cent. of ash. A complete analysis of this ash is as follows:

	Per cent.
Silica	5.413
Alumina	3.262
Sesquioxide of iron	0.479
Lime	0.243
Magnesia	0.007
Phosphoric acid	0.012
Potash and soda	traces.
	9.416

Another analysis of the ash in Connellsville coke is as follows:

	Per cent.
Silica	44.64
Alumina	25.12
Sesquioxide of iron	22.73
Lime	6.95
Magnesia	1.91

The chief objection to most of the impurities is their reduction of the calorific value of coke. The phosphorus and sulphur, however, exert a decidedly deleterious effect upon the iron if coke is used in furnace or cupola work. For these reasons cokes that are low in ash, if high in either of these ingredients, are of but little value.

The amount of water in coke is also an important consideration, and all commercial cokes contain more or less of it. As cokes are usually dried before analysis, analyses do not usually indicate the amount of water present in the coke in the condition in which it is supplied to purchasers. It should not exceed 2 or 3 per cent., but at times it is as high as 5 or 6 per cent. As the presence of water reduces the value of coke as a fuel, it should be as low as possible. This water comes chiefly from that used in quenching the coke, and it is therefore of the greatest importance that some method should be used which shall leave the least water. The evidence seems to indicate that coke quenched in the oven, as in the bee-hive plan, contains less water than that quenched outside, as in the Belgian.

The amount of oxygen in coke is also a very important consideration, especially if it is to be used for smelting iron, where the process is essentially the combination of the oxygen of the ore with the carbon of the coke; and if the coke has already absorbed a portion of its oxygen, its heat value is reduced to that extent. Cokes that, so far as ash is concerned, would seem to be of a fair quality are, more frequently than is supposed, really inferior fuels, by reason of the presence of water, oxygen, and other substances, which not only reduce the percentage of carbon, but in some cases require the expenditure of a portion of what remains in the coke to expel the injurious elements.

From what has been said, it is evident that when it is necessary to arrive at the approximate true value of a coke, without actually testing it in furnaces, which is oftentimes expensive and sometimes involves great risk, not only is a thorough analysis necessary, but a most careful consideration of its physical structure should be made.

In various parts of this report, especially in the chapters on "Coking and Non-coking Coals" and those devoted to the coals and cokes of specified localities, a number of analyses of coke are given. In this place it is only necessary to bring together analyses of certain of these cokes that may be regarded as types, giving here only analyses of industrial cokes, or those made commercially, and not in the laboratory. It is not claimed that these analyses are of the best specimens, or of average specimens even, unless so stated, and it is fair to presume that parties in selecting specimens for analysis would not select the poorest.

ANALYSES OF EUROPEAN INDUSTRIAL COKES.

<table>
<tr><th>Localities.</th><th>Mine or seam.</th><th>Fixed carbon.</th><th>Ash.</th><th>Sulphur.</th><th>Hydrogen.</th><th>Oxygen.</th><th>Nitrogen.</th><th>Authority.</th></tr>
<tr><td>English:</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Durham</td><td>Browney, average</td><td>91.580</td><td colspan="2">6.86</td><td>0.230</td><td>1.310</td><td>...</td><td>I. Lowthian Bell.</td></tr>
<tr><td>Do</td><td>do</td><td>91.490</td><td colspan="2">6.32</td><td>0.460</td><td>1.730</td><td>...</td><td>Do.</td></tr>
<tr><td>Do</td><td>South Brancepeth</td><td>92.980</td><td colspan="2">4.61</td><td>0.300</td><td>2.110</td><td>...</td><td>Do.</td></tr>
<tr><td>Do</td><td></td><td>93.150</td><td>3.95</td><td>...</td><td>0.720</td><td>0.900</td><td>1.28</td><td>Richardson.</td></tr>
<tr><td>Belgian</td><td>Mons basin</td><td>91.300</td><td>6.20</td><td>...</td><td>0.330</td><td colspan="2">2.17</td><td>M. de Marsilly.</td></tr>
<tr><td>Do</td><td>do</td><td>91.590</td><td>5.89</td><td>...</td><td>0.470</td><td colspan="2">2.05</td><td>Do.</td></tr>
<tr><td>Do</td><td>Séraing</td><td>80.850</td><td colspan="2">16.610</td><td>0.510</td><td>2.130</td><td>...</td><td>I. Lowthian Bell.</td></tr>
<tr><td>German</td><td>Westphalia</td><td>85.060</td><td colspan="2">6.400</td><td>0.860</td><td>7.680</td><td>...</td><td>Dr. F. Muck.</td></tr>
<tr><td>Do</td><td>do</td><td>91.772</td><td colspan="2">6.933</td><td>1.255</td><td>0.040</td><td>...</td><td>Do.</td></tr>
<tr><td>Do</td><td>do</td><td>83.487</td><td colspan="2">10.309</td><td>0.787</td><td>5.467</td><td>...</td><td>Do.</td></tr>
<tr><td>Do</td><td>Saar</td><td>86.460</td><td colspan="2">8.540</td><td>1.980</td><td>3.020</td><td>...</td><td>Do.</td></tr>
</table>

ANALYSES OF AMERICAN INDUSTRIAL COKES.

Localities.	Mine or seam.	Carbon.	Ash.	Sulphur.	Moisture.	Volatile matter.	Authority.
Pennsylvania:							
Connellsville	Broad Ford	89.576	9.113	0.821	0.300	0.460	McCreath.
Do	Coketon	89.150	9.650	1.200	....	....	B. Crowther.
Irwin's	Penn Gas Company	88.240	9.414	0.962	....	1.384	Carnegie Bros. & Co.
Allegheny mountains	Bennington "B"	87.580	11.360	1.060	....	....	McCreath.
Blossburg	Arnot Seymour vein	84.760	13.345	0.998	0.175	0.722	Do.
Allegheny River	Lower Freeport	85.777	11.463	2.107	0.330	0.623	Do.
Beaver county	Hulmes & Bro	84.727	12.636	1.994	0.100	0.633	Do.
West Virginia:							
New River	Quinnimont	93.850	5.850	0.300	....	....	J. B. Britton.
Do	Fire Creek	92.180	6.680	0.618	0.110	....	Do.
Do	Longdale	93.000	6.730	0.270	....	....	*C. E. Dwight.*
Do	Nuttallburg	92.220	7.530	0.910	....	....	Do.
Ohio:							
Leetonia	Washingtonville	93.750	5.380	0.870	....	....	*Professor Wormley.*
Steubenville	Shaft coal	90.630	8.380	0.270	....	....	Dr. Wuth.
Tennessee:							
Tracy City	Sewanee	83.364	15.440	0.142	....	....	*Land.*
Whitesides	Kelly	94.560	4.650	0.790	....	....	Etna Coal Company.
Rockwood	Roane Iron Company	84.187	14.141	0.182	....	....	Land.
Alabama:							
Warrior field	Pratt seam	88.224	11.315	0.563	0.362	0.990	Professor McCalley.
Cahaba field	Helena seam	84.035	15.216	0.445	0.683	0.660	Do.
Illinois:							
Big Muddy	Mount Carbon	88.180	10.070	0.610	....	0.930	Thomas M. Williamson.
Colorado:							
El Moro	El Moro	87.470	10.680	0.850	1.85		
Crested Buttes	Crested Buttes	92.030	6.620	....	1.35		

COAL-WASHING.

"Coal-washing," so called, is, strictly speaking, not washing, but the separation or classification of the coal and its impurities so far as the latter are mechanically mixed with the coal and can be separated from it. To accomplish this separation advantage is taken of the different specific gravities of the coal and of the schist, pyrites, and other minerals that form the impurities. The action of all coal-washing or coal-cleaning appliances depends upon this difference.

It will be evident that the problem of coal-washing is an extremely complicated one. The specific gravity of the coal itself as it comes from the mine varies greatly, that from the same pit and the same lump varying oftentimes from that of pure coal to that of shale, while the shale or schist presents all the intermediate gravities from that of schist to that of coal. In washing it is evident that the denser coals and lighter schists would be classified together, and thus the object of cleaning would not be accomplished, or the process would be so wasteful as to make the washing a commercial failure.

The problem is still further complicated by the impossibility of securing a uniformity in the sizes of the particles of the coal. In washing it is necessary that the particles to be treated do not exceed a certain size, which varies somewhat with their character. Preliminary screening, and in some cases crushing, are therefore necessary, but after such screening there will be certain sizes smaller than the mesh through which it has passed, including considerable dust. This dust will be carried away with the water, and is either wasted or requires some arrangement for settling and collection, while the difference in weight of the different sizes causes the heavier pieces to arrange themselves with the lighter impurities. In addition to these difficulties, some coals are of such a character that washing, though necessary to remove slate and similar impurities, is so wasteful of the coal and certain constituents of the same as to forbid its use. As is explained in the portion of this report treating of Ohio coke, the Steubenville coal is not washed, because of the large amount of "mineral charcoal" contained in it that would be wasted in the process. The same is true of some coals poor in hydrogenous matter.

It will be evident from the above that coal-washing is an operation that does not admit of any definite rules suitable for general application with absolute reliability in all localities, and the advisability of washing and the method to be employed are subject to variations dependent upon the collieries, the localities in which they are situated, the commercial conditions affecting them, and the amount of water available. It is thus evident that coal-washing, in the language of M. Marsaut, "is a function of a great number of altogether independent variables, among which no sort of connection exists." For this reason it cannot be expected that any one washing apparatus can prove perfectly satisfactory for all cases.

In this report it will not be possible to enter into a full discussion of coal-washing, but only to indicate in a general way its principles, methods, advantages, and disadvantages. (*a*)

In Germany the cleaning of coal is done to some extent by the use of air. The coal, first crushed quite small, is fed into a strong inclosed current of air, the larger and heavier particles being first deposited by the winnowing and the smaller and lighter carried farther on. This process could, no doubt, be economically adopted in sections where water is scarce, and perhaps with some coals that would be hurt by cleaning with water.

Though the method by air may be used in exceptional circumstances, coal-washing is generally done by the use of water. The washing or separation is effected either—

First, by a running stream of water, carrying the materials along with it and depositing them according to their specific gravity;

Second, by the fall of the materials through water; or,

Third, by the action of an upward current of water.

In most recent works on coal-washing the first method is ignored, as being too antiquated and wasteful; but as this plan of washing by a stream of water in boxes or sloping spouts or troughs is still largely used in England, and is regarded with great favor, a description is given, though the process is wasteful, and can only be used to advantage where water is plenty and coal cheap and dirty.

The accompanying cut shows in plan and section one form of the trough-washer. (*b*)

The method of operation of this trough or channel will be readily seen. The trough is constructed of wood, varying in length from 30 to several hundred feet, in width from 2 to 4 feet, and in depth from 12 to 15 inches. This trough is divided into compartments by means of cross-boards or flash-boards from 4 to 6 inches high and from 10 to 25 feet apart. A screen of wire-cloth or perforated sheet-metal is placed at the lower end of the trough for separating the washed coal from the water before the coal reaches the car or hopper in which it is shipped. Sliding gates are provided in the sides of the trough for clearing it from stones and other impurities. The operation is as follows: The slack coal, with a large and constant stream of water, is introduced at the upper end of the channel. By the action of the water-current the fragments of coal, having a lower specific gravity than the impurities, are carried down and over the steps, while the impurities find their way to the floor of the trough, and are kept back by

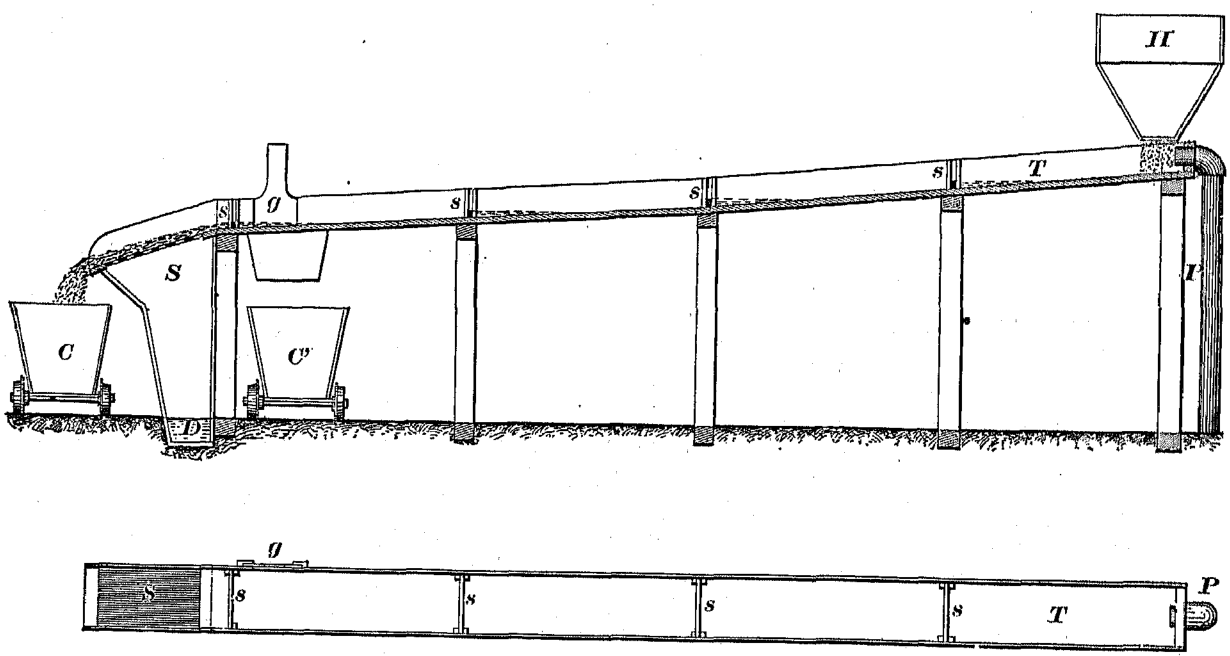


FIG. 4.—Plan and section of trough-washer.

the cross-boards. To prevent the larger pieces from becoming too much mixed with the impurities, especially behind the steps, the material is stirred with poles. These operations are continued until the bed of the channel above the cross-boards is filled with impurities to near the top of the boards, when the inlet of slack is stopped. The water is kept flowing and the material stirred from the upper dam downward until all the coal has been floated away, leaving only the impurities at the bottom of the trough. Then the sliding gate near the screen is opened, and communication with the coal-hopper is closed and established with the outside. The steps are removed, commencing with the lowest one, and the channel is washed out to be ready for a new round. The cleaning of the trough has

a Those desirous of investigating this subject further are referred to Rittinger's *Lehrbuch der Aufbereitungskunde*, Ernst und Korn, Berlin, 1867, M. Marsaut's treatise reprinted in *Engineering*, London, vol. 29, 1877, and to *Coal-Washing Machinery*, by S. Stutz, Pittsburgh, 1881.

b For this and the cuts of the Hartz jig I am indebted to Mr. David Williams, of the *Iron Age*, New York.

to be repeated every three or four hours, varying with the amount of impurities in the coal, and during this cleaning the process of separation is interrupted. The effectiveness of this washer depends largely upon the carefulness of the workmen.

According to Mr. Stutz, the amount of coal that can be washed in a day in a single trough from 40 to 50 feet long varies from 2,000 to 3,000 bushels, according to the amount of impurities. About five men are required, and, estimating labor at from $1 to $1 25 a day, the expense of washing per ton is from 10 to 12 cents. The volume of water used is very large; it may be estimated at from 300 to 400 gallons per minute for a single trough.

In the cut on the preceding page *H* is the coal-hopper, from which the slack is let into the trough *T*, water being supplied by the pipe *P*, flowing down over the steps *s*, carrying the coal with it over the screen *S* into the car *C*. The water, after passing through the sieve, passes out by the drain *D* to catch-tanks, where the fine coal is allowed to settle. The gate *g* at the side of the trough is used for removing the impurities which drop into the car *C'*.

In the washers most commonly in use the separation is accomplished by the action of an upward current of water, or by washers of the third class, and in constructing them for the cleaning of a given coal it is important to know and regulate two things:

First, the size of the pieces of coal to be operated upon.

Second, the speed of the upward current of water.

Herr Rittinger, who has so fully investigated the mechanical dressing of ore, has shown that if spherical pieces or grains of any substance of different diameters and different densities are allowed to fall through still water they severally acquire in an exceedingly short time a limiting velocity of descent, which thenceforth continues uniformly for each separate piece respectively. By a series of calculations and experiments he has deduced a formula giving the mean uniform velocity of irregular-shaped pieces of any substance, coal in particular, when falling through water or when subjected to the action of an ascending regular current of water. This formula is:

Velocity in feet per second $= 1.28 \sqrt{D(d-1)}$, d being the density of the material and D the diameter of the mesh riddle or screen, or virtually the diameter of the pieces to be operated upon. From this formula tables can be deduced showing the rapidity of the fall of coal and its impurities when these are known for a given coal, which will indicate what must be the sizes of the coal to be operated upon, and consequently the size of the mesh of the riddle used in separating prior to washing.

This will also indicate the velocity of the upward current of water, as it must be proportioned to the size of the material treated. M. Marsaut has shown that if a mixture of coal, slate, etc., is subjected to the action of an ascending current of water the following conditions may occur:

1. The speed of the upward current may be exactly equal to the limiting velocity of fall of the pieces of coal or other substances through still water, in which case the corresponding fragments will remain stationary.

2. The speed of the current may be greater than the limiting velocity, and in this case the fragments will rise with a velocity equal to the difference.

3. The speed of the current may be less than the limiting velocity of the pieces, and in such case the latter will fall with a velocity also equal to the difference.

In all cases, however, the formula of Rittinger is applicable.

It is evident that the velocity of the upward current should neither exceed nor fall short of certain limits. A current too strong will interfere with the classification, while a velocity inferior to that of the larger or denser fragments of coal will be incapable of separating the latter from the surrounding pieces of slate. It is also necessary that the upward current be uniform throughout the whole of the mass of material, since differences in this respect at particular points will produce unequal displacement of pieces, which otherwise would fall with equal velocity.

In the action of the washers about to be described the coal is fed upon screens, and the upward current permits of the arrangement according to gravities and in accordance with the law of Rittinger. The particles do not have the same independence of motion as when falling through water isolated from each other, but any interference is obviated if sufficient time and space are given for the action of this intermittent current.

M. Marsaut divides coal-washing machines into three principal classes:

1. Machines in which the water absolutely filters through the coal to be washed. This is the case of the old piston or Hartz jig in its different forms, whether worked by machinery or by hand.

The filtering action of the water comes fully into play in this machine, and slack of poor quality may be treated to advantage, since the action caused by the back suction is brought to bear upon the fine particles of impurities forming the slimes. For this very reason, however, it causes a serious loss of combustible matter in the shape of fine coal, and the apparatus is therefore wasteful.

We give on page 76 cuts of two forms of the Hartz jig, in one of which the coal is removed from the sieve by rakes or by hand (Fig. 5), and in the other by the revolving scraper R (Fig. 6). The operation of these machines will be readily understood from an inspection of the drawings.

The water flows into the settling-tank through the pipe *p*, and by the action of the plunger *P* is given a reciprocal motion, which forces it up through the sieve *S*, into which the coal is let from the hopper *J*, in Fig. 1.

As the water flows over the delivery bridge *b*, with each stroke of the piston it carries with it into the channel *c* a certain amount of coal. By means of the screw *a*, the impurities are let into compartment *d*, through which they reach the outside through the opening *e*. As is already explained, this process is somewhat wasteful. Mr. Stutz estimates that from 150 to 200 bushels per square foot of surface of screen can be washed per day of ten hours, requiring a volume of water of from 5,000 to 6,000 gallons, or from 30 to 35 gallons per bushel of washed coal. Generally two men are sufficient to wash from 2,500 to 4,000 bushels per day, making the expense from 3 to 5 cents per ton.

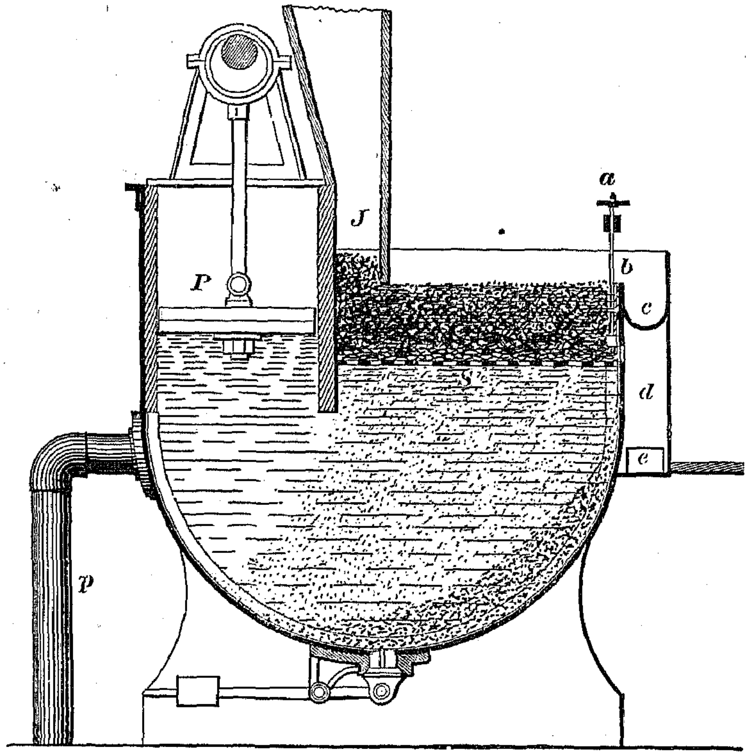


FIG. 5.—Hartz jig.

2. Machines in which the filtration of water through the material is either entirely or partially obviated, and in which a continuous or intermittent ascending current of water produces the separation.

These washers possess the great advantage over the former class of machines of effecting a more complete separation, and thus the loss of fine coal is reduced to a minimum. They also require far less driving-power for their working. Great improvements have been made in the arrangements of some of these machines, in view of the quantity of washed coal produced and in the economy of attendance; but here I may state that at some places the free delivery or overflow of the washed coal is the source of the greatest trouble, as the machine is pushed and made to deliver more than can be properly washed. The discharge by the overflow being controlled by the quantity of water let into the machine, some machines are forced to turn out double the intended amount; and the consequence is that the coal is badly washed. A certain time is of absolute necessity to obtain a good cleansing, and the quantity of washed coal has a direct and invariable relation to the surface of the sieve of the washer.

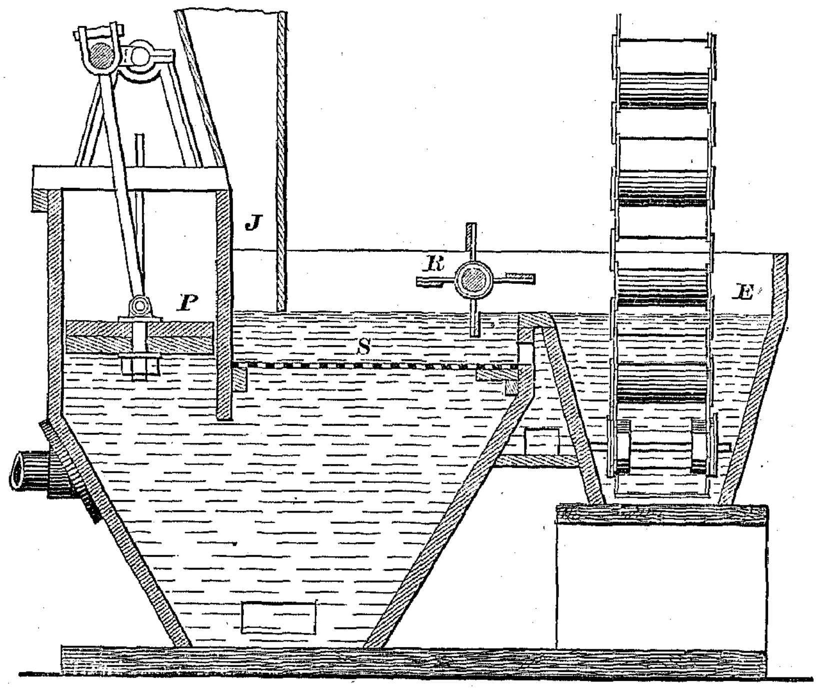
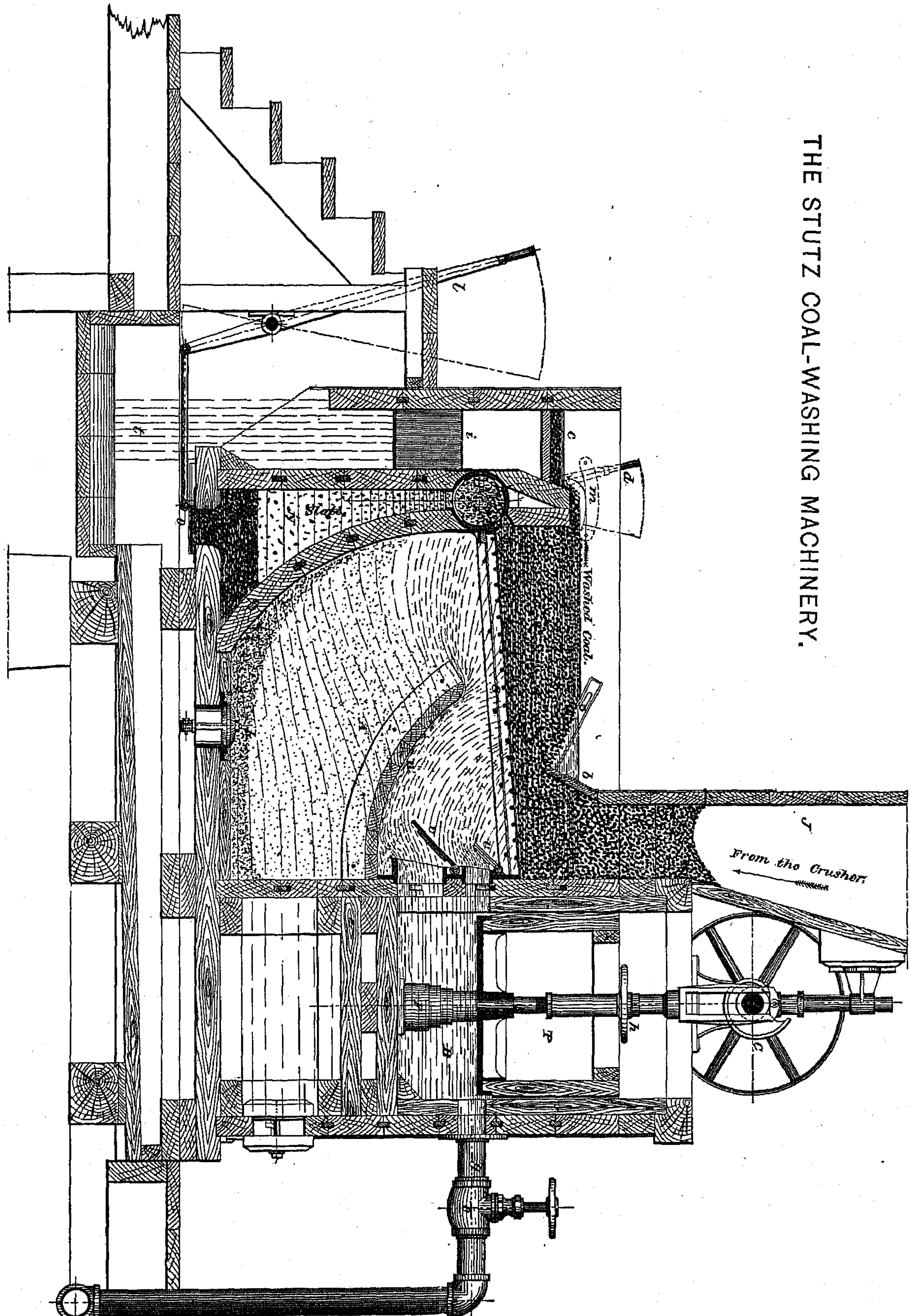


FIG. 6.—Hartz jig, with revolving scraper.

An illustration is given on page 77 of the Stutz form of this class of machines, most largely in use in this country.

Two wooden boxes, *A* and *B*, strongly bolted together by tie-rods and flat iron bands, contain, respectively, the sieve *S* and the plunger *P*. The water is taken into the machine by the pipe *g*, and the current is produced by means of the plunger *P* and a differential cam, *C*, and its action may be easily regulated to suit the size of any substance. In this apparatus the yoke of the cam *C* is connected with the plunger-rod by a swiveled screw-nut, and can be raised or lowered, according to the current required. This is done by the hand-wheel *h*. *F* is a spring-buffer, to limit the downward stroke of the plunger, and *v* are valves to prevent the filtration or back-suction of the water. The arrangement of the curved partition *n* has for its object to direct the fresh water upward through the sieve and the layer of the material, and to prevent its being mixed with the slimy and muddy water of the lower portion of the box *A*. Coal is brought upon the sieve from the bin *J* by passing below the gate *b*. At each fall of the plunger *P*, a certain volume of fresh water being driven through the openings of the valves *v* into the box *A*, a sudden rise of the water-level and the layer of the material is thus produced, causing an equal volume of water to flow over the bridge *m* into the channel *c*, carrying with it an amount of pure coal. Before leaving the washer the mixture of water



THE STUTZ COAL-WASHING MACHINERY.

FIG. 7.

and coal passes over a drying sieve, *i*, leading the coal to the elevator buckets, while the water goes out through the meshes of the sieve and flows out below. By their greater density the pieces of slate, sulphur, etc., form the layer immediately upon the sieve *S*, and, being forwarded at the same time as the coal, will pass through the valve *H* into the slate-chamber *N*. The inlet of the slate into the valve *H* is regulated by the lever *d*, according to its percentage. From the chamber *N* the impurities are let to the outside of the gate *o*, worked by the lever *l*, and reach the trough *t*, from which they are carried away by the waste water. The fine particles of slate, etc., forming the slimes, settle below the partition *n* and are discharged by the valve *k*. The use of a differential cam for the working of the plunger allows the material after each stroke the necessary time to deposit, according to gravity. An eccentric or crank cannot produce the same movement. The usual size of the sieve is 3 feet by 4 feet 6 inches, or by 4 feet 9 inches, hence its surface is 13½ or 14¼ square feet. Washers with one or more sieves are constructed. An apparatus with two sieves of the above dimensions can prepare from 200 to 300 tons of slack per day of ten hours. The amount of water required varies from 12 to 25 gallons per bushel (76 pounds) of coal, and sometimes even more, according to the percentage and nature of the impurities contained in the material.

Mr. Stutz estimates that from 3,000 to 4,000 bushels of coal can be washed per day in this machine with a simple screen. At the works of Charles H. Armstrong & Son, at Pittsburgh, an apparatus of two screens 3 by 4 or 4½ feet washes daily from 6,000 to 7,000 bushels. A 4-gallon pump, running at from 50 to 60 single strokes per minute, furnishes the necessary water, thus giving from 20 to 25 gallons of water per bushel of coal.

The labor needed to the above amount is:

One man attending engine and washing-machine, at	$2 50
One man attending to boilers, etc., at	1 25
Total	3 75

or from 1½ to 2 cents per ton.

At the works of the Colorado Coal and Iron Company, near El Moro, in Colorado, where the coal is crushed and washed in this machine, the cost of crushing and washing 200 or 250 tons daily is from 4½ to 5⅝ cents, as will be seen from the following statement, the amount washed being, as above given, 200 or 250 tons:

Interest per day on $12,000 at 10 per cent. per annum	$4 00
Coal, oil, packing, etc	1 50
One machinist	2 50
One fireman	1 75
One laborer	1 50
Total	11 25

The third method of washing of M. Marsaut includes a number of plans of sorting by equivalents, none of which are in use in this country, and which it is not necesssary to refer to here.

As many of the coals of Illinois especially require washing, I give a cut and description of a washer that has been especially adapted to these coals. It is the Osterspey jig, improved by the Messrs. Meier, of Saint Louis. (See page 79.)

The upper box A B is composed of 2-inch plank, feathered at the joints, and bolted to a stout bottom frame of 4-by-8 inch scantling and an upper frame of 3-by-6 inch scantling. The bottom frame serves to rest it on floor timbers, either lengthwise or crosswise, as most convenient. The lower box C, also of 2-inch plank, fits into it, secured by heavy feathers and bolts. It is pointed toward the bottom to cause the fire-clay, etc., to settle around the mud-valve M, through which it is discharged.

The upper box has a rear chamber, B, with plunger P, and is separated from the forward chamber A, with screen bottom *g g*, by means of the diaphragm E. This is double, and admits the water-supply pipe W and the mud-valve rod *r*, both of which pass through the cross-plate *e*, which forms a fulcrum for the mud-valve level *m* and a support for the housing H, carrying the two shafts. The forward shaft carries a pulley, S, and a slotted cross-head, T, in which a T-headed bolt, I, is clamped at a point giving the desired stroke. A sleeve on the bolt I works in boxes sliding freely on the guides G attached to the rear shaft, thus giving a quick down-stroke and slow up-stroke to the crank K and the plunger P.

The bed *g* is made of fine wire-cloth, supported on coarser netting, or on perforated plates of iron, braced by six small angle-irons crosswise and two heavier ones lengthwise, held down by key-bolts, *a a*, and resting on a narrow cast-iron frame, *f f*.

By driving back the keys and unshipping the six bolts *a a* the whole bed can be lifted out and replaced in ten minutes. By having a few extra bed-screens on hand, we avoid delays in case of choking up by fire-clay, or in case of repairs to screens.

The screen-plates perforated with fine holes in use in Europe will not answer, frequently choking up with fire-clay several times a day.

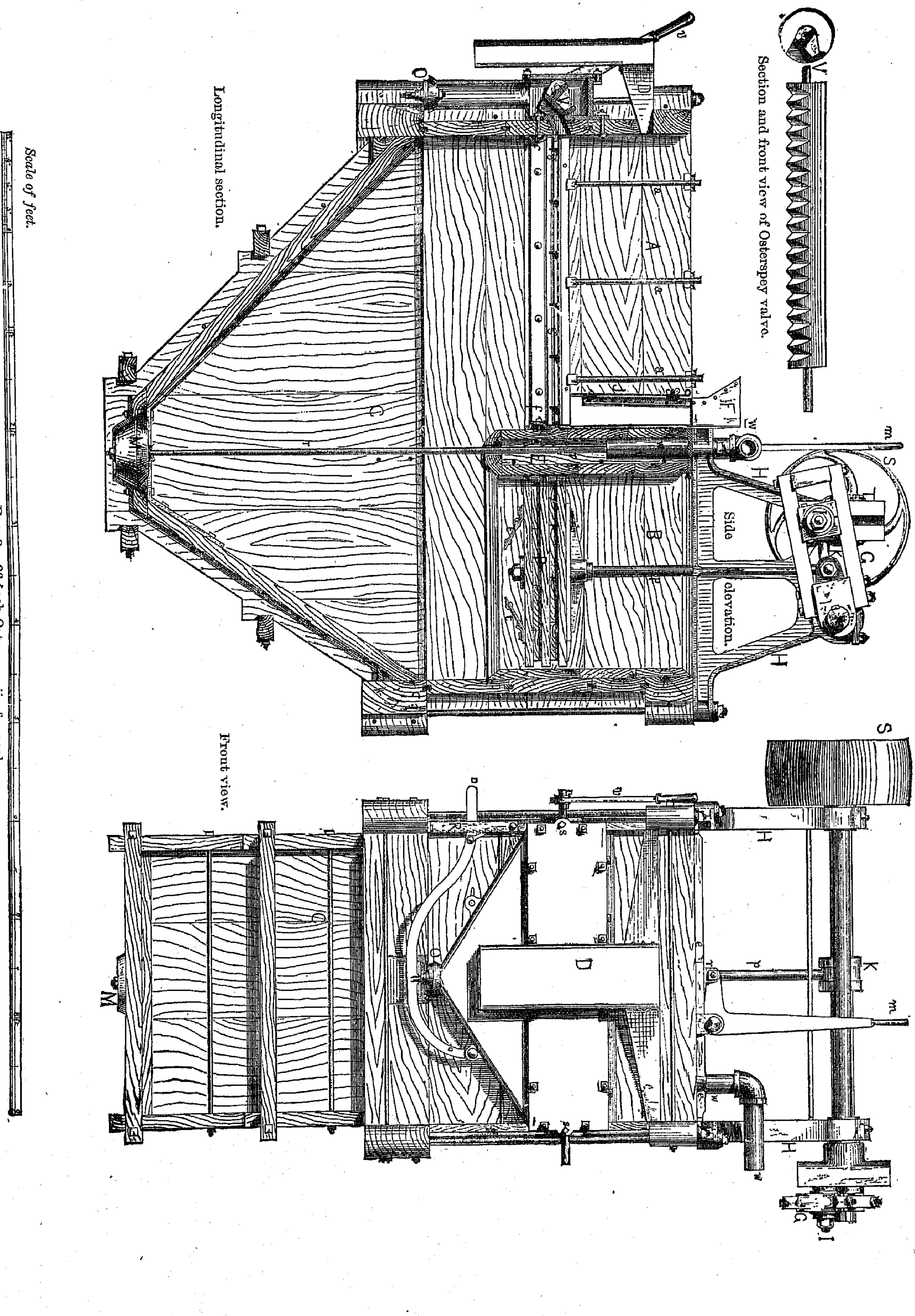


FIG. 8.—36-inch Osterspey jig for coal.

The coal is fed through a hopper, F, and under the slide J, which regulates the quantity. It is jigged along the whole length of the screen *g*, the washed coal discharging over the bridge through the hopper D. The slates and dross pass through a slot flush with the bed-screen and through the valve V, and drop into a pocket, from which they are occasionally drawn by means of the slate-valve O.

The main valve V consists of part of the periphery of a cylindrical roller which has been perforated by a number of parallel triangular prisms. This presents to the discharge-slot a number of triangular openings, giving, equally distributed over its entire width, just as much free area as is required to continuously discharge the dross as it accumulates on the bed *g*.

When it becomes necessary to open the valve O, the valve V is momentarily closed by turning the lever *v* until V presents its smooth cylindrical surface to the discharge-slot. Then O is thrown suddenly open, the dross washes out, O is as rapidly closed, and V slowly returned to the position previously determined as giving the required discharge area. The plunger has valves, *t t*, of such opening as to prevent any possibility of suction. The feed-pipe *w* supplies water when needed to fill the jig or to supply the waste when V is closed and O open. The value of having the lower discharge as far as possible from the feed and of the full width of the screen, whether in washing coal or concentrating ores, will appear upon reflection, and can be shown by ocular demonstration when working a jig.

A certain number of strokes will be necessary to create regular layers of materials of different gravities, and within certain limits this classification must be improved with each stroke. These layers will, in uniform action of the upward currents of water, be of equal thickness across the jig, *i. e.*, perpendicular to the line of travel.

The quantities washed, preserving the quality above given, varied from 30 pounds for the smallest size, I, to 223 pounds for size IV per hour. On Pennsylvania coal the same machinery could easily furnish 60,000 pounds per hour.

As to the advantage and benefits of coal-washing, there can be no doubt that in many cases where the coal to be coked is impure, containing a large mixture of slate or sulphur in the form of pyrites, it is advantageous to crush and wash previous to coking. It would also be advantageous to wash slack in which there is a large amount of the same impurities, but it by no means follows that all coals would be improved by washing, even though the impurities might to some degree be removed. The Kemble Coal and Iron Company, at Riddlesburg, Pennsylvania, which for some time used a modification of the Berard washer, abandoned it some two years ago. The operation carried away the hydrogenous matter, which made a desirable physical structure and afforded heat in the coke oven. Other works in this country using other forms of washers have ceased washing. A coal with a large surplus of pitchy matter can be washed without serious loss; in fact, in some instances, with gain; for it has frequently too much of this matter, and a reduction is advantageous. This fact should be carefully borne in mind in deciding as to the advisability of washing a coal to reduce the percentage of ash. Connellsville coal, no doubt, would be injured by washing, and the small excess of ash or slate in the coke, if aluminous, is not objectionable in a furnace working mainly with lake ores. It may be that in this statement will be found an explanation of the fact that a good many cokes, with what might be termed an excess of ash but a good physical structure, are superior as blast-furnace fuels to cokes with a less amount of ash.

In some cases, where washing is not advisable, it has been found that simply crushing the coal prior to washing has a very good effect. Mr. I. Lowthian Bell stated before the Iron and Steel Institute of Great Britain that he found crushing the Durham coal prior to coking a great advantage, and in many parts of England the coal is thoroughly crushed before coking.

In many sections of this country the coal is washed prior to coking, and it has been found to be decidedly advantageous. Illustrations of this are given in the remarks on coking in the different states. It is also found in some sections of Europe that great advantage results from careful washing. Washers are largely used in Belgium, and in Westphalia especially a great deal of ingenuity has been expended in improving the methods of washing.

COKE AS A BLAST-FURNACE FUEL.

By far the largest part of the coke made in the world is consumed in blast-furnaces in smelting iron; indeed, it has been with its use in these furnaces that its manufacture in any country may be said to have begun. It was Darby's successful use of coke at Coalbrookdale that made coking an English industry, as was the use of the Connellsville coke at the Clinton furnace of Graff, Bennett & Co., at Pittsburgh, the beginning of the wonderful development of that region.

It is impossible to say how much of the pig-iron of this country is made with coke as a fuel, either in whole or in part. In 1879 1,438,978 net tons, out of a total of 3,070,875, were made with bituminous coal as a fuel, either raw or as coke; in 1880 1,950,205 tons out of 4,295,414. Nearly all this was with coke. In addition to this some of the iron reported as made with charcoal is made with charcoal and coke mixed, while a much larger proportion of the anthracite iron is made with part coke. Mr. James M. Swank, special agent, states that 2,128,255 tons of coke were used in the manufacture of pig-iron in the United States in the census year, while 2,615,182 tons of anthracite and 53,909,828 bushels of charcoal were used in the same time.

The use of coke has been rapidly increasing since 1871. For some years prior to this date considerable coke had been used, but a large portion of the iron made with bituminous fuel was made with raw coal. In 1872 the Lucy and Isabella furnaces, at Pittsburgh, went into blast, and the results obtained with Connellsville coke undoubtedly attracted attention to this fuel. No other furnaces in the world, except the Edgar Thomson, also located at Pittsburgh, and using the same coke, have ever made so much iron in a week. The results obtained led some anthracite furnaces at the time of the great strike in the anthracite region in 1875, which cut off the supply of coal, to try coke, with most remarkable results, and a practice begun from necessity was continued from choice. The make of the furnaces has been largely increased, accompanied with an economy of fuel.

It is not within the scope of this report to enter into a discussion of the relative value of coke and anthracite; but it may be said that the superiority of coke as a furnace fuel is largely due to its physical structure. It is not as dense or as pure a fuel as anthracite, but its physical conditions are such as to especially fit a good, well-made coke for a blast-furnace fuel. (*a*) It bears a heavy burden, retains its shape as it passes down the furnace, does not splinter or grind away, allows the passage of the blast, is swift in combustion, and acts with great energy. Some of these characteristics explain how it improves the yield of anthracite furnaces. Its swift combustion and energy assist the slow-burning anthracite, and by retaining its shape without splintering it gives a better draft to the blast.

While not entering into a discussion of the relative merits of these two fuels, it may be well, however, to indicate the results obtained in practice, both when used singly and when used together in the furnace. The following table, furnished by Messrs. Taws & Hartman to Mr. James M. Swank, special agent, and published in his report on the statistics of iron, page 173, shows the consumption of fuel, together with other necessary details for comparison, at eleven prominent coke and anthracite furnaces in the United States, taken from an average of six consecutive weeks' work in each case in the summer of 1881:

Details.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.	No. 11.
Bosh .... feet..	18	11	13	20	18	16	15	17	20	20	17
Height .... do....	78	60	65	75	70	70	56	70	80	75	65
Fuel to ton of pig-iron .... pounds..	2,227	2,264	2,314	2,900	2,987	2,822	2,603	2,357	2,490	2,677	2,618
Carbon in fuel, ... per cent..	85	94	85	82	88	85	87.4	83	85	87	86
Ore to ton of pig-iron .... pounds..	2,610	4,816	4,099	2,481	4,480	4,239	3,413	3,920	3,971	4,212	4,362
Rolling-mill cinder to ton of pig-iron ...... do....	1,030	....	....	1,230	....	....	488	....	....	....	....
Limestone to ton of pig-iron .... do....	1,546	1,355	1,815	1,756	2,240	1,815	1,050	983	1,339	2,309	1,107
Quality of pig-iron .... numbers..	1, 2, 3	3, 4	1	1, 2, 3	1, 2	2	2, 3, 4	3	1	2, 3	1, 2 Bessemer.
Heat of blast	1,150°	750°	1,050°	1,150°	1,100°	1,348°	876°	1,371°	1,080°	765°	750°
Kind of fuel used	Coke.	Coke.	Coke.	Coke.	Anthracite.	Anthracite.	Anthracite.	$\frac{1}{3}$ coke, $\frac{2}{3}$ anthracite.	Coke.	$\frac{1}{8}$ coke, $\frac{7}{8}$ anthracite.	$\frac{1}{8}$ coke, $\frac{7}{8}$ anthracite.
Average weekly production of pig-iron in tons of 2,268 pounds.	700	170	562	986	470	292	403	359	$1,274\frac{1}{2}$	527	390

a In a recent discussion as to the requisites of a good blast-furnace fuel, Mr. John Fulton, in a letter to the *Keystone Courier*, mentions four characteristics as essential: 1. Hardness of body; 2. Well developed cell structure; 3. Purity; 4. Uniform quality.

PART V.—OVENS.

COKING IN PILES.

Coking is essentially a process of distillation, its object being to expel from the coal the volatile matter at the least expenditure of its carbon, which remains in the form of a firm, hard coke. To accomplish this three methods of coking are employed:

First: In piles or mounds, a method analogous to that used in the manufacture of vegetable charcoal.

Second: In rectangular kilns, having brick or stone sides, and entirely open at the top.

Third: In closed kilns or ovens of brick or stone.

The simplest of these methods, and the least expensive in plant, but the most wasteful and expensive in coal, is that in heaps, piles, or mounds. This method is termed in various parts of the world "coking in coke-fires", on "coke-hearths", "in ricks," "racks," and "on the ground". The earliest method of coking in piles, and one evidently suggested by the method employed by charcoal-burners in charring wood, is in a small circular heap. The coal, which must be in lumps, is piled in the open air in circular mounds, the lumps being set on their sharpest angle, so that air-spaces are left, and as small a surface as possible touches the ground. This process is at first conducted without any external covering and with a free access of air. As it progresses the burning is checked at the proper time by the application from the base to the top of a coating of breeze coke, or earth. When sufficiently burned, all access of air is prevented, the burning stopped, and the coke is allowed to cool. The coke heap is always erected on the same "station", where sufficient breeze soon accumulates for damping the fire in the heap. This process is very wasteful, the yield often being less than 50 per cent. It is still used, however, especially in sections where the demand for coke is small and its manufacture has just begun.

Instead of the circular heap, pyramidal piles, with narrow, rectangular bases, are sometimes used. This method is preferred to that of the small circular heap, as it is not so wasteful, and a much larger amount of coal can be operated upon. Usually these piles are quite long, oftentimes from 150 to 200 feet, and instead of one long pile, frequently a number of short ones, parallel to each other, are used. At the Coalbrookvale iron works, in South Wales, pits or piles 12 feet wide by from 3 feet 6 inches to 5 feet high in the center are burned, the pits containing from 2 tons 10 hundred-weight to 3 tons per linear yard. This method seems to have been used at an early date in the history of coking in England. Mushet, in an article written prior to 1800, thus describes the method as practiced at that time:

> In preparing pit-coal for the blast-furnace, well understood among manufacturers by the term "coking", flat surfaces are appropriated. These are firmly beat and puddled over with clay, so as to pass the necessary cartage without furrowing or loosening the earth. These spaces form squares, more or less oblong, and are called hearths, upon which the pieces of coal are regularly placed, inclining to each other. Great care is taken to place each piece upon the ground layer on its acute angle, in order that the least surface possible may come in contact with the ground. By this means large interstices are preserved for the admission and regular communication of the air necessary to excite and effect complete ignition.
>
> The quantity of coke charred in one heap or hearth is various at different and even at the same works. About 40 tons of coal form the smallest fires, and some hearths again will admit of 80 or 100 tons. The length of the fire is in proportion to the quantity of coal built; the breadths and heights are also subject to no determined standard, but are from 30 to 50 inches high and from 9 to 16 feet broad. In building each fire they reserve a number of vents, reaching from top to bottom, into which the burning fuel is introduced. This is immediately covered by small pieces of coal beat hard into the aperture; these repress the kindling fire from ascending, and oblige it to seek a passage by creeping along the bottom, which is most exposed to air. In this progress the fire of each vent meets, and, when united, it rises gradually and bursts forth on all sides at once.
>
> If the coal contains pyrites, the combustion is allowed to continue a considerable time after the disappearance of smoke; the sulphur then becomes disengaged, and part of it is found in flowers upon the surface of the heap. If the coal is free from this hurtful mixture, the fire is covered up in a short time after the smoke disappears, beginning at the foundation and proceeding gradually to the top.
>
> The length of time necessary to produce good coke depends upon the nature of the coal to be coked and the state of the weather. In fifty, sixty, or seventy hours the fire is generally completely covered over with the ashes of char formerly made. The coke, thus entirely secluded from the air, soon cools, and in twelve or fourteen days may be drawn and wheeled to the furnace. (a)

The practice at the present time in England where piles are used does not differ much from that described by Mushet. In preparing these heaps the ground is first leveled and covered with a layer of small coal, from 12 to 16 inches thick, upon which the large coal is stacked, inclining toward the middle in such a manner as to leave air-passages all through the inside of the pile, the outside being covered with a layer of small coal. The piles are ignited on the top at intervals, and the process of coking is conducted downward. If the heaps are long, the coking is facilitated by a series of chimneys that are formed by building into the pile stakes of wood, which, after being withdrawn, are replaced by burning coals. The fire is thus communicated to the mass in so many

(a) Mushet *On Iron and Steel* (London, 1840), page 53.

parts at the same time that ignition soon becomes general, and coking proceeds throughout the whole extent. As the flames ascend upon the outside of the pits, the coker damps them with wet coke dust until the coal is completely coked throughout, when the wet dust is carefully packed down, the entrance of air is prevented, and the fire deadened. The heap is allowed to remain two or three days to cool, care being taken to supply it with thicker covering on the side that is exposed to the wind than on that which is opposite to it. When the fire is nearly extinguished the coke is withdrawn and quenched by the use of water. This method, as well as that in circular heaps, is far from economical, and the coke made is by no means uniform.

In this country the method of coking (*a*) in open heaps or pits, as practiced by the Cambria Iron Company in the Allegheny Mountain region, is probably the most systematic and thorough of any. The accompanying engraving gives a good idea of the pits used.

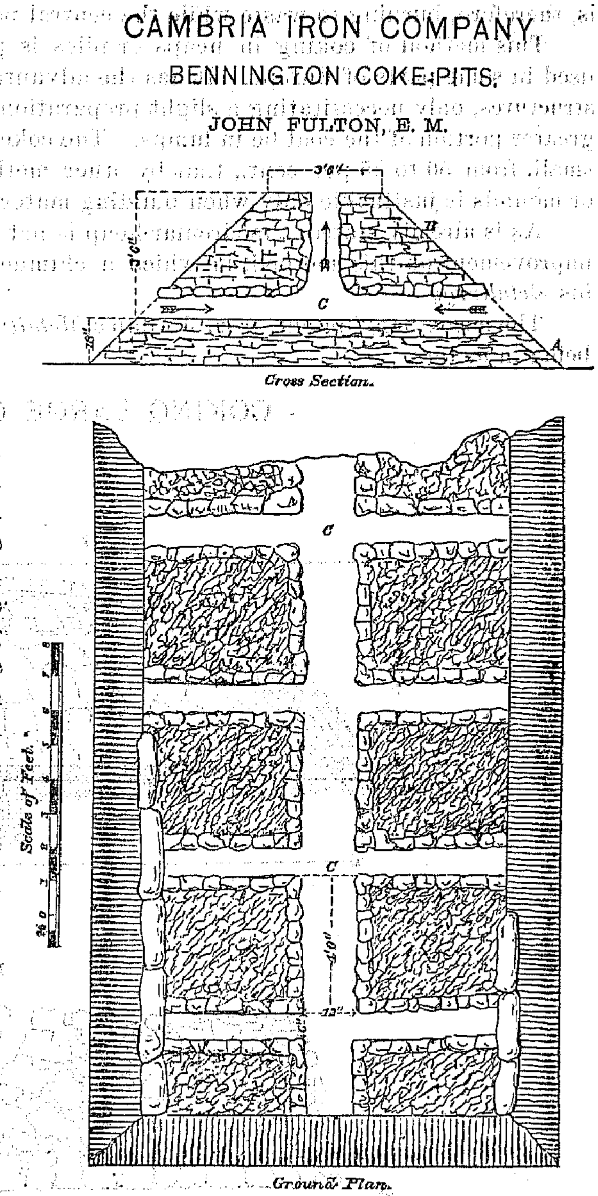


FIG. 9.

The coke-yard is prepared by leveling a piece of ground and surfacing it with coal dust. The coal to be coked is then arranged in heaps or pits, with longitudinal transverse and vertical flues, sufficient wood being distributed in these to ignite the whole mass. Beginning on a base of 14 feet wide, the coal is spread to a depth of 18 inches, A. On this base the flues are arranged and constructed as shown in the plan, the coal being piled up, as shown in section B. These flues are made of refuse coke and lump coal, and are covered with billets of wood. When the heap is ready for coking, fire is applied at the base of vertical flues, C, C, igniting the kindling-wood at each alternate flue. As the process advances the fire extends in every direction, until the whole mass is ablaze. Considerable attention is required in managing this mode of coking—in diffusing the fire evenly through the mass, in preventing the waste of coke by too much air at any place, and in banking up the heaps with fine dust as the operation progresses from base to top.

When the burning of the gaseous matter has ceased, the heap is carefully closed with dust or duff and nearly smothered out in this way. The final operation is the application of a small quantity of water down the vertical flues, which is quickly converted into steam, permeating the whole mass. This gives coke, if carefully applied, the least percentage of moisture.

The time necessary for coking a heap with the Bennington coal is from 5 to 8 days, depending mainly on the state of the weather.

The coke made in this way is beyond any doubt excellent, and its yield accurately determined at Bennington and Hollidaysburgh is as follows:

BENNINGTON.

	Gross tons.
Coal used	56.87
Coke drawn	33.63
Loss	23.24

Yield of coke, 59.1 per cent.; loss, 40.9 per cent.; 1.69 tons of coal to 1 ton of coke.

HOLLIDAYSBURGH.

	Gross tons.
Coal used	63.80
Coke drawn	38.02
Loss	25.78

Yield of coke, 59.6 per cent.; loss, 40.4 per cent.

a Report L of the *Pennsylvania Geological Survey*, p. 122.

The yield at both these places is substantially the same, 59 per cent., exhibiting a loss of 24 per cent. of the carbon contained in the coke. The surface of the heap is coked before the central parts are reached, and the outside is, therefore, burning to waste while the central portions are but little acted upon.

This method of coking in heaps or piles is practiced to but a small extent in this country, though it is still used in some parts of Europe. It has the advantage of requiring but little capital and the erection of inexpensive structures, only necessitating a slight preparation of the surface; but it has the disadvantage of requiring that the greater portion of the coal be in lumps. The coke obtained is lacking in uniformity, and the yield is comparatively small, from 50 to 55 per cent., that by other methods yielding from 60 to 70 per cent. The manufacture in piles or mounds is justifiable only when building material is high-priced and coal very cheap.

As is already stated, the circular heap is not used to any great extent in England at the present time, and an improvement on this method, in which a chimney is used in the centre of the pile, is thus described by Percy in his *Metallurgy*.

The accompanying cut, from Jordan's *Metallurgy*, shows the circular pile in use in France, the measurements being in meters.

COKING LARGE COALS IN CIRCULAR PILES.

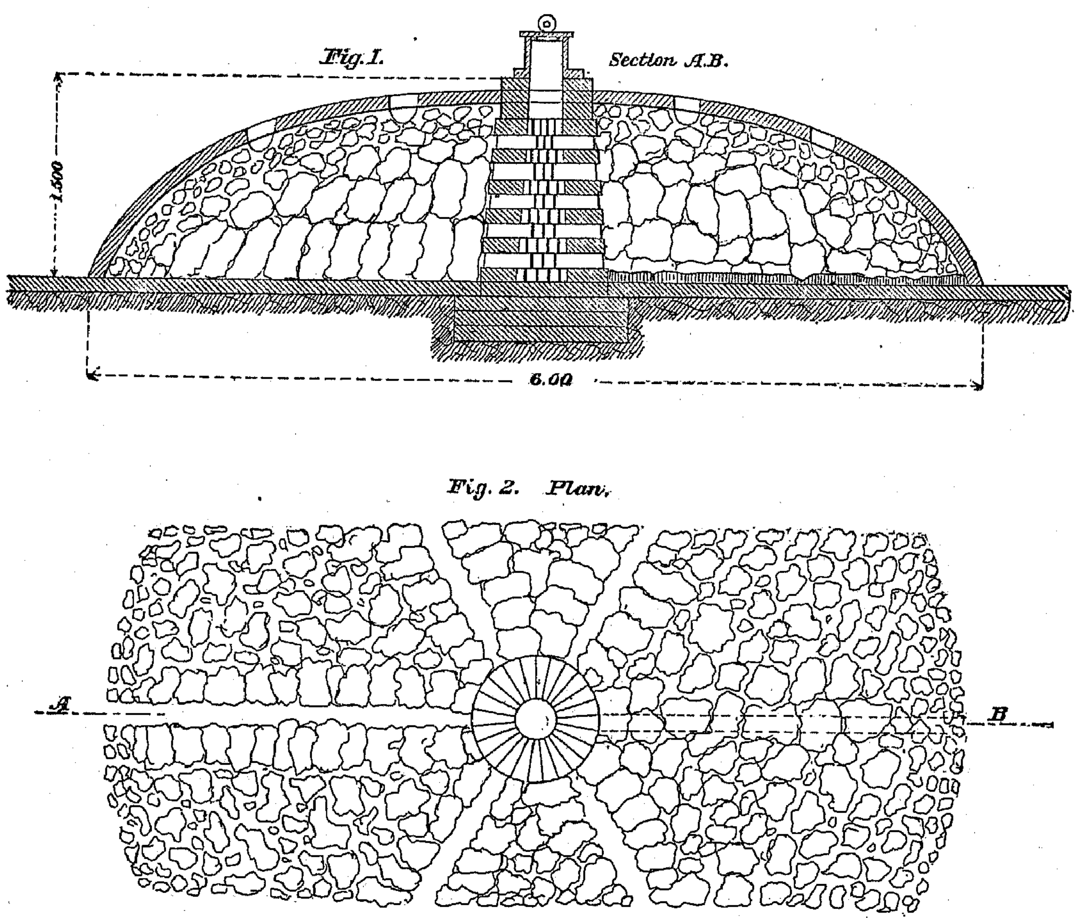


FIG. 10.

A large circular pile, containing some 20 tons of coal (1 ton=2640 pounds), is stacked around a chimney built of bricks without mortar. The diameter of this pile at the base varies, in some instances being 18 and in others 30 feet, the height at the center nearest the chimney being from 5 to 6 feet. The bricks in the chimney are laid so as to afford openings for the escape of gas and flame, a large flat brick at the top serving as a damper, and the heat of the pile is sufficient to vitrify the surface of the bricks of which the chimney is built and to bind them together. The outside is covered with wet coke dust. The pile is lighted at the top from the chimney, and combustion is downward through every part of the mass. Too free combustion is checked by wet coke dust applied with a spade, including the space around the bottom previously left uncovered, and, if necessary, the chimney is left unclosed. About 10 days are required for coking by this method, water being thrown upon the pile ...wn. In some cases, instead of lighting from the top, coals are dropped to the bottom of the chimney, ...d from the middle of the bottom outward.

COKING IN OPEN KILNS.

As coking in the circular mound developed into the bee-hive oven or kiln, so coking in long rectangular piles resulted in the open kiln. This process of coking in open kiln is only the long-pile process, with permanent walls for retaining or holding the sides.

The kiln as used in Silesia, which is shown in the accompanying cut, consists of a rectangular inclosure, having two parallel side walls of brick, *a a* (Fig. 2), floored with brick set on edge, beneath which is a layer of glassy blast-furnace slag, broken small, through which proper drainage is secured. The inner surface of the walls and the bottom is of fire-brick; the outer wall may be of red brick or stone. The walls are 5 feet high, 8 feet apart in the clear, and from 44 to 60 feet long (Prussian measure). In each of the walls *a* is a series of openings, *c* (Fig. 1), 2 feet apart and the same distance above the floor of the kiln, so placed that those on one side of the kiln are opposite the corresponding ones on the other. From each of these openings rises a vertical chimney, *d*.

COKING IN RECTANGULAR KILNS.

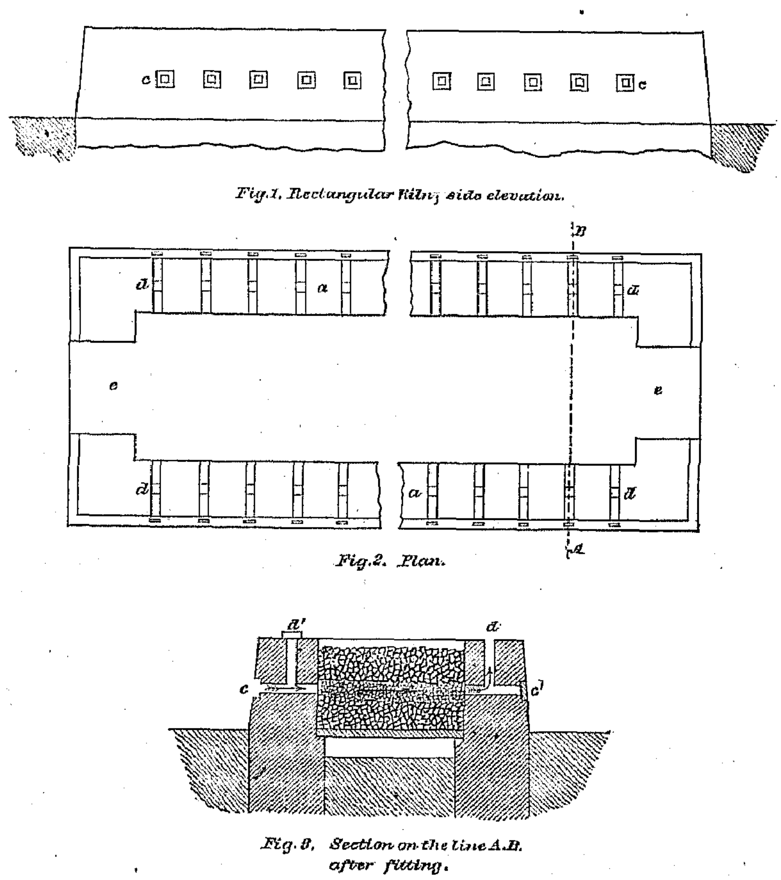


FIG. 11.

Dr. Percy thus describes the process of charging, firing, and burning this kiln:

The space *e* between the two walls at one end of the kiln is bricked up, and through the opposite end coal slack is wheeled in, spread over the bottom, watered, and stamped down so as to form a solid stratum 9 inches thick, or as high as the lower edges of the openings *c c*, etc. Indeed, this height may be made 2 feet with advantage, if the coal be suitable. Pieces of wood 6 inches in diameter at one end and 4 at the other, and in length equal to the width of the kiln, are then passed through the openings in one wall, so that their opposite ends may respectively lie in the corresponding openings in the other wall. Wetted coal slack is spread over the pieces of wood and stamped carefully down. The kiln is then filled up with slack, which at every 6 inches of additional height should be watered and stamped down. Brand well remarks that the mode of filling just described is very hard work when the kiln exceeds 40 feet in length. After the filling is completed the top of the coal is covered with a layer, 2 or 3 inches thick, of coal dust, or, failing this, of loam. The end opening, through which the kiln has been charged, is at last bricked up. The pieces of wood are now carefully drawn out, and thus a series of channels is left in the coal, upon the maintenance of which the success of the process essentially depends. Should an injury occur to any of the channels at the commencement it can hardly be repaired afterward. Before lighting the kiln all the chimneys on one side are stopped by placing a brick, *d′*, on the top of each, those on the opposite side being left open, while on the second side the openings or draught-holes are stopped by bricks, *c c′* (Fig. 3), the holes on the first side being left open, as at *c* (Fig. 1). The kiln is now lighted by means of sticks of easily inflammable wood introduced into all the openings *c* on the left. A current of air is established through the transverse channels in the coal. After the lapse of six or eight hours the fire will have reached the opposite ends of these channels, when the chimneys on the left, *d*, and the draught-holes on the right, *c*, must be opened, and the chimneys on the right, *d*, and the draught-holes on the left, *c*, must be closed. This, however, should only be done when the fire has regularly spread through the entire extent of the channels. Special care in this respect at the commencement will prevent further trouble afterward. According as the weather is, stormy or settled, the direction of the currents of air through the kiln may be changed from every two to four hours. Should the coking be found to proceed irregularly, it may be necessary to keep open some of the chimneys on one side longer than others, and, consequently, not to change the direction of all the currents at once. Irregularity in the coking may result either from the quality of the coal or negligence in piling it in the kiln; and in either case the yield will be diminished.

In the management of the process the work of the coke-burner is reduced to keeping open the transverse channels in the coal by raking out any pieces of coal which may fall into them and obstruct the passage of the air, and by preventing their sides from sintering together. For this purpose he uses a slender iron rod, somewhat bent at one end. The reopening of a channel which has once become stopped is attended with much difficulty, and is generally impracticable; and if several neighboring channels are closed, the process is thereby much impeded. In windy weather the draught of air through the kiln must be carefully regulated by closing, in a greater or less degree, the chimneys. Any cracks which may occur during the process in the covering on the top of the coal must be well stopped in order to prevent the ascent of currents through them. The proper regulation of the draughts through the kiln has an important influence upon the quality as well as the yield of coke.

In about eight days the process will be completed, as may be known by the escape of white flame from the chimneys and the hardness which is perceived on plunging an iron rod through the cover on the top. All the openings must now be closed, and in the course of two days afterward the fire will have become gradually extinguished. One of the end walls is now taken down and the coke removed. The coke at the height of the channels will be separated into two distinct layers; that in the upper layer especially is remarkably beautiful [*sic*], dense, hard, and when carefully withdrawn is frequently in pieces 3 feet long and 1 foot in diameter. The yield per 7.768 English cubic feet of coal ranged from 241.25 to 261.87 pounds avoirdupois. The loss in weight is 20 per cent. of the coal, an amount which, according to the quality of the coal, is often much reduced.

The theory of coking by this method is perfectly intelligible. The coal surrounding the transverse channels is ignited and through these are established currents of air. Heat is thus developed partly by the combustion of the coal in the vicinity of the channels and partly by that of the volatile products arising from its destructive distillation. The coking will therefore proceed simultaneously upward and downward. No currents, as has already been stated, can ascend through the coal above the channels if the kiln be properly attended to, and obviously none can descend from above; consequently, the air which sustains combustion can only enter the kiln through the lateral draught-holes. At the conclusion of the process an accumulation of tarry matter always occurs immediately under the coal at the top of the kiln, which would further tend to prevent the descent of air from above as well as the ascent of currents from below; and it is there that the most solid coke is produced.

In South Wales and in other districts kilns of this kind have been erected of not less than 15 feet in width from wall to wall, measured within. The transverse channels have been made by suitably piling lumps of coal without the use of poles. When the coal is of different sizes, it is advantageous, according to Mr. Rogers, to place the smaller pieces toward the top of the mass. In these larger kilns the mass becomes well ignited in from 24 to 36 hours. During the process the workman walks on the top of the coal, and from time to time he thrusts through different parts of the surface an iron bar, which is easily pushed down until it reaches the mass of coke, and in this way the height to which the coking process has reached is satisfactorily ascertained. If he finds it to have progressed higher at one part than at another, he closes the chimney communicating with that part, and so retards the process there. When the mass has been coked up to the top, which takes place in about seven days, it is quenched with water, and the coke is withdrawn in the manner already described.

Mr. Rogers writes to Dr. Percy as follows:

The new kilns have proved entirely successful; they are already in use at some of the largest iron works in the kingdom, and are being erected at a number of other works. The great saving in the first cost of oven, economy in working and maintenance, increased yield, and improved quality of coke, will probably soon cause this mode of coking to supersede the others now in use. The kilns are most advantageously made, about 14 feet in width, 90 feet in length, and 7 feet 6 inches in height, this size of kiln containing about 150 tons of coal.

Mr. Rogers asserts that an outlay in plant of only £4 was required to produce one ton of coke per day from the Welsh coals, and that the cost of working does not exceed 6*d.* per ton. In some places the coal has been actually tipped into the kiln from the colliery wagons, and the coke wagons were afterward run into the kiln to be loaded direct from the mass of coke produced, thus reducing the labor to a minimum. The kilns need only to be built of rough rubble-work, with a plain lining of fire-brick, and without any iron work, so that the expense of repairs amounts only to a small sum.

As to the results from the use of these kilns, Dr. Percy makes the following statement:

In 1859 I visited several of the large iron works in South Wales, where these kilns had been tried, and I inquired particularly concerning the results. Opinions on this subject were certainly not concordant. At the Dowlais iron works they were erected, and, after repeated trials, abandoned. Mr. Menalaus, the manager of those works, considers them to have been a complete failure, and informs me (June, 1873) that, after making allowance for the water in the coke, the yield was very bad indeed.

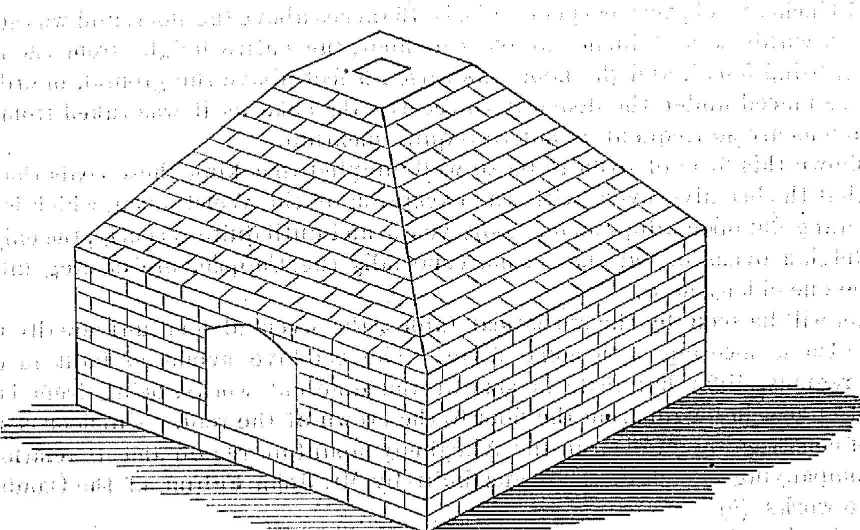
The Ebbw Vale Iron Company also made a trial of them, and Mr. Adams, the then manager, informed me that they appear to be suitable for one kind of coal, but that for their usual good coal they are wasteful and expensive. Much of the large coal which is used to form the transverse channels is burned away, and, as he quaintly observed, "You might hunt badgers through the coke." At the Pontypool works I inspected one of these kilns from which the coke had been partially drawn, and I remarked that a good deal of the coal in the vicinity of the draught-holes appeared to have burned away. Some of these kilns were much higher than I had seen elsewhere. Experiments have been made at these works with kilns having double rows of draught-holes on each side; but I was informed the result was unsatisfactory.

THE BEE-HIVE OVEN.

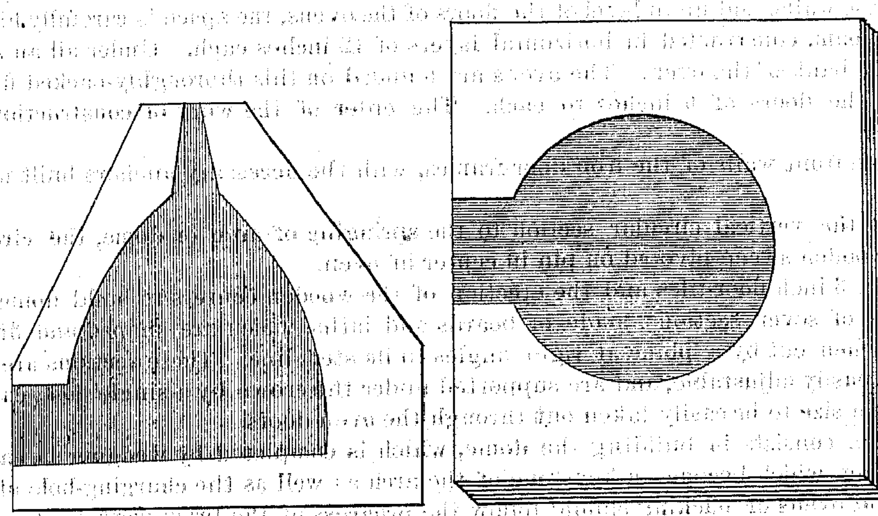
The method of coking in piles can be used to advantage only in exceptional cases. Where coal is very cheap and oven-building materials are expensive, or in those localities where the demand for coke is light, or in cases of a large increase in demand at high prices, especially if this increase promises to be temporary, coke can be burned to advantage in heaps; but under ordinary circumstances of manufacture and condition of the market it is too wasteful of coal, requires too much care in management, and the product is too uncertain in quality and variable in density to make this method economical or desirable. It therefore happens that as the demand for coke increases and becomes reasonably certain the long pile gives place to the open kiln and the circular mound or heap to the bee-hive oven, which is evidently such a mound or heap with a permanent covering of fire-brick, instead of a temporary one of slack and clay or wetted coke dust.

The earliest form of the closed kiln or oven is the "bee-hive", so named from its general resemblance to the old-fashioned conical-shaped bee-hive. This is a flat-bottomed, vaulted chamber of fire-brick or other refractory material, with an opening in the top or crown, through which the oven is charged, and which also serves as an outlet for the waste products of combustion, while an opening or slightly-arched doorway in the side at the bottom serves as an inlet for the air necessary for combustion, and also for drawing the coke. In the process of coking this opening is either built up with bricks, or a door with a frame-work of iron filled in with fire-brick is used, the frame-work being either hinged or raised by a chain passing over a pulley with a counterpoise weight at the other end, or a pair of hinged doors may be used. These ovens are not usually built separate, but in long banks, and sometimes in blocks of two banks, back to back, with the spaces between the ovens filled in with some material that retains the heat, generally in this country loam, thereby preventing radiation of the heat left in the walls, keeping them at a more even temperature, and facilitating the coking process.

PLAN OF COKE OVENS NEAR NEWCASTLE-UPON-TYNE.



A.D. 1765.



Section. FIG. 12. *Ground Plan.*

The bee-hive oven in its earlier and most common form was solid-walled and vaulted, as described above. In the improvements, however, that experience showed to be advantageous both on the score of economy of time and material, and in some cases of product, this has been changed. The bee-hive developed and extended into a long oven, in some cases oval, in others rectangular, while the solid wall of the oven was pierced with flues, and finally developed into that form of oven known as the "Belgian". These forms will be treated of in another part of this report.

The earliest recorded use of coke ovens is in 1763, in Newcastle, England. M. Jars, in a work published in 1774, says:

There are nine kilns at Newcastle, upon the edge of the river, to destroy the sulphur contained in the coal and reduce it to what is called "cinders and coaks". The principal use of the cinders is to heat the malting-kilns; it is also used by a silversmith. I have seen a manuscript upon "the art of working coal-mines", in which the first attempts in this manufacture were given as of very ancient date, being made in England. (*a*)

The cut on page 87 shows the plan of these ovens as figured by M. Jars.

Horne's statement regarding the use of coke ovens near London (see page 54) is of about the same date as this of M. Jars.

From this time quite frequent notices of the use of ovens are found. About A. D. 1800 coke ovens were found on the outcrops of the Brockwell coal-seams, at various pits in the southern part of the county of Durham, the coke being used for breweries and founderies. Parkes, in his *Chemical Catechism*, published early in the present century, describes ovens of this kind which were used at the Duke of Norfolk's colliery, near Sheffield. He describes each oven as a circular building, 10 feet in inside diameter, with a floor of common brick, set edgewise. The wall, which was 18 inches thick, rose perpendicularly 19 inches above the floor, and was surmounted by a conical roof, of which the apex within was 22 inches above the floor, the entire height from the floor to the top of the arch, outside measure, being 5 feet, and the floor was raised 3 feet above the ground, in order that a wheelbarrow or low wagon might be placed under the doorway to receive the coke as it was raked from the oven. After this notices of the use of ovens are so frequent as not to require mention.

Experience has shown this form of oven to be so well adapted to coking those coals that have furnished most of the English coke that the bee-hive oven, with the exception of the Welsh oven, which is either a modified bee-hive or an inclosed rectangular open kiln, was for many years, and until quite recently, the only one used in England. Latterly, however, Belgian ovens of various forms, especially the Coppée, are coming into some favor, though the bee-hive is still the one chiefly used.

In this country, as will be seen by the statistical tables, the oven almost universally in use is the bee-hive, though the Belgian also is meeting with some favor. The bee-hive ovens, as built in the Connellsville and Allegheny Mountain regions, differ but little in size at the different works, being from 11 to 12 feet in inside diameter and from 5 to 6 feet in height from the floor to the crown of the roof. The floor is slightly inclined to the front. The method of constructing an oven in the Allegheny Mountain region and its relation to wharf and tracks are shown in the accompanying sketch of the ovens built by Mr. John Fulton, of the Cambria Iron Company, at their Bennington coke works. (*b*)

These ovens are circular, the diameter being 11 feet 6 inches, and are 6 feet high from the level of the floor to the crown of the dome, the charge filling the oven as far as the dotted line in the left completed oven. The radius of the dome, which is built up on centers, as the right-hand oven shows, is 6 feet 10 inches, the diameter of the charging-hole being 1 foot.

The Bennington coke ovens are placed in a double row, inclosed between two strong retaining-walls of sandstone masonry. Between these walls, and up to level of the floors of the ovens, the space is carefully filled and compactly rammed with clay and loam, constructed in horizontal layers of 12 inches each. Under all an ample drain is laid longitudinally under the bank of the oven. The ovens are founded on this thoroughly-packed filling, having a fall in their floors toward the doors of 6 inches to each. The order of the work of construction consists of four consecutive operations:

1. The setting up on front walls of the iron door-frames, with the necessary anchors built up with the shaped jamb-brick.

2. The building of the vertical circular section to the springing of arch or dome, the circular line of oven being preserved by a wooden sweep pivoted on pin in center of oven.

3. The laying of the 3-inch floor-tiles and the erection of the wooden centers to build dome of ovens. These wooden centers consist of seven sections, made of boards and laths, which are shaped and fit together like the sections of an orange when cut by a plane at right angles to its stem-line. These sections are supported at the base by small benches, easily adjustable, and are supported under the crown by a single post, capped by a circular collar, and are made of a size to be easily taken out through the oven doors.

The fourth operation consists in building the dome, which is completed by wedging in carefully and firmly the annular charging-ring, which becomes a keystone of the arch as well as the charging-hole of the oven.

The filling in around ovens or backing should follow the progress of the brick-work as closely as possible, the material, clay and loam, being laid down in horizontal layers of 12 inches deep, and carefully rammed. The track on the top of the ovens is laid with iron tie-pieces, and has a gauge of 6 feet, to allow space for lorrie containing 5 tons of coal. The water for quenching the coal is supplied by 3-inch cast-iron pipes, with taps and hose between the ovens.

a I quote from a paper by Mr. A. L. Steavenson, published in the *North of England Institute of Mining Engineers' Transactions*, vol. viii, 1860, pages 111, 112.

b These drawings are taken from the *Report of the Bureau of Statistics of the State of Pennsylvania* for 1877 and 1878.

MOREWOOD COKE COMPANY.

GROUND PLAN AND SECTION OF BANK OVEN.

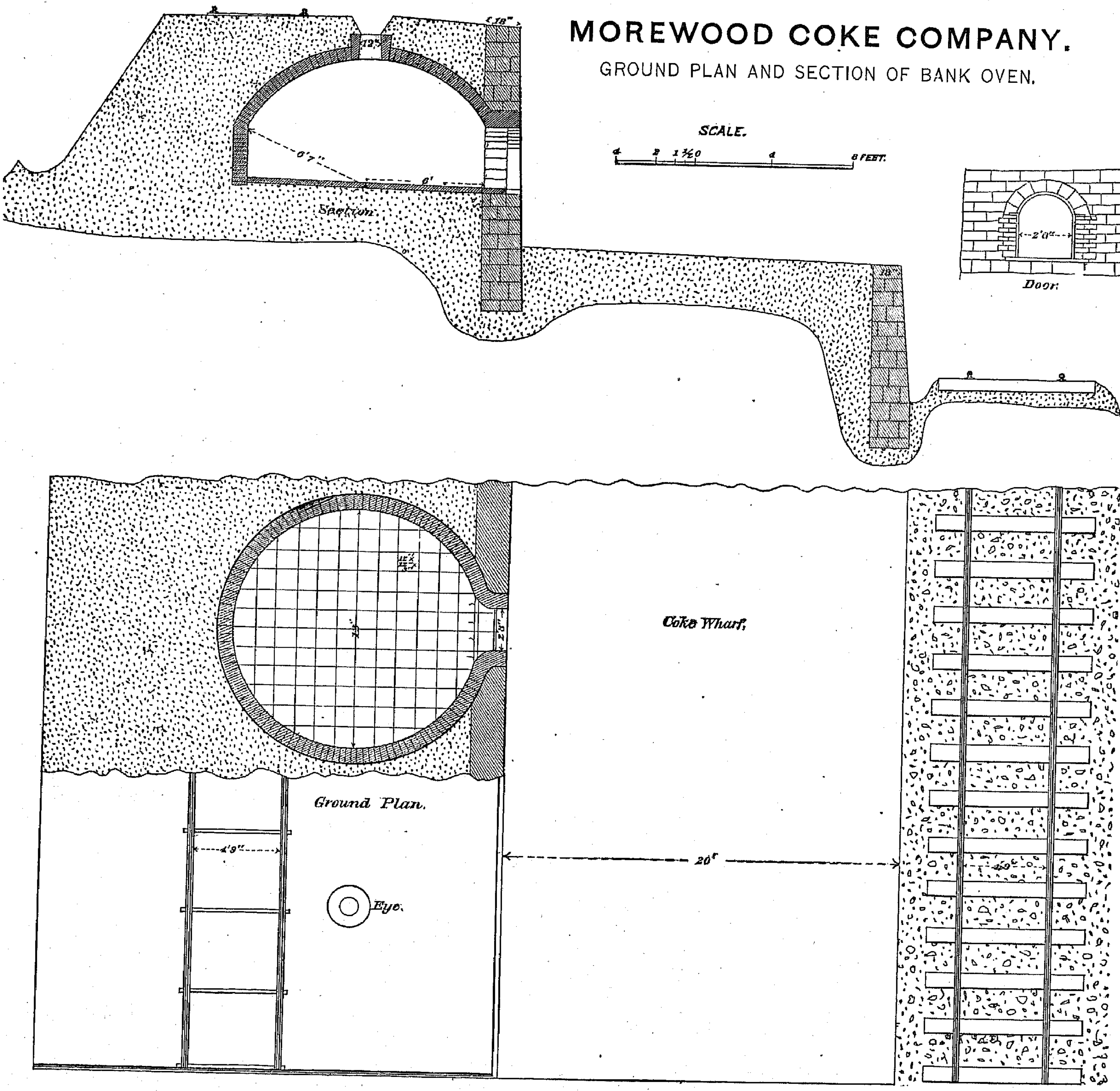


FIG. 15.

As showing the style of these ovens, as well as the general plan of a coke works in the Connellsville region, I have given the accompanying cuts, representing the works of the Morewood Coke Company, limited, one of the latest and best built coke works in that section. The method of operating these ovens in the Connellsville region is quite simple, and may be taken as the usual practice in this country. The coal is generally brought to the oven in lorries holding each a full charge, 125 bushels, for 48-hour furnace coke. The lorrie is run to the charging-hole on a railroad over the top of the oven, and the coal is dumped through the hole in the crown of the roof and carefully leveled by means of a long iron hook inserted into the door. This door is bricked up and plastered or daubed, except some small interstices at the top, so as to admit only sufficient air above the coal to carry on combustion. The heat which the oven acquired in the preceding operation is always sufficient to ignite the new charge, combustion being carried on by the entrance of the air through the doorway, and the coal soon begins to emit aqueous and sulphurous vapors, followed by a thick, black smoke and reddish flame all around the sides. At this stage of the process the gases are particularly offensive. The heat of the oven at this time is a low red. In a few hours the mass of burning coal cracks downward, enabling the volatile matter below the surface to pass off, and by its ignition to generate additional heat for carrying on the process. In about 12 hours a clear, bright flame prevails over the entire surface, which increases almost to a white heat. Basaltiform columns are formed, which allow the gases to rise as the heat ascends. Finally the clear, bright flame dies off gradually, and the coke becomes a glowing red mass. Now the sooner the oven is quenched and drawn the better, for the coke will continue to take up air in spite of every precaution, and the red-hot coke will waste, lose heat, and become inferior as a fuel.

A description of the coking process in bee-hive ovens in the Durham region is thus given by Mr. Meade:

> When the oven is refilled with a proper charge, the coal is fired at the surface by the radiated heat from the roof, enough air being admitted to consume the gases given off by the coal, and thus a high temperature is maintained in the roof of the oven. The coal is by this means melted, and those portions of it which, under the influence of a high temperature, can of themselves form gaseous compounds, are given off, forming at the moment of their liberation small bubbles, or cells. The coke now left is quite safe from waste, unless a further supply of air is allowed to have access to it. At this stage of the process the coke assumes a pentagonal form and columnar structure. When the coke is left exposed to heat for some time after it is formed it becomes harder and works better, from being less liable to crush in the furnace or to decrepitate on exposure to the blast.

In England the coke was formerly drawn from the bee-hive oven in a heated state and afterward cooled by water thrown on with buckets outside, but this method has been discontinued, and the coke is cooled inside of the oven by water thrown upon it, either from buckets or with a pipe and hose. The only drawback to the method of quenching is that the oven is cooled by the contact of the water with the hot bricks. It is generally believed, however, that coke cooled inside of the oven absorbs less water than when cooled outside. The quenching causes the coke to separate or crack open and facilitates the drawing.

In drawing the coke from the oven the usual plan is to pull it out, piece by piece, with long bars of iron turned up at the end, similar to a large poker or hook. This method is the only one that can be used in the ordinary bee hive oven. Other methods of discharging by what are termed "drags" are used in modified forms of the bee-hive oven and in the Belgian oven.

It will be noted that the coking process is essentially a process of distillation, the oven being the retort, the heat in the bee-hive oven necessary for volatilization after it is once heated being derived from the burning of the volatile products, and the heat remaining in the walls of the oven instead of being applied from the outside. Some of the heat is at the expense of the carbon of the coal, as it is impossible to prevent the destruction of a portion of the carbon by the admission of the air necessary for combustion, though it is avoided as much as possible. The combustion is maintained over the top of the coal, and the coking or distillation proceeds in the bee-hive oven downward from the top, and also slightly inward from the sides, the current of inflammable gas and vapor arising through the coal and meeting the air admitted through the doors above the burning in what may be called the "combustion chamber", until the lowest stratum is converted into coke. It is evident that air should be admitted only over the top, as, if the air enters below or through the coal, coming in contact with it when hot, a portion will be consumed, and the coking will not be effected exclusively by the heat resulting from the combustion of the volatile products, as it should be, but largely at the expense of the coke, which should be avoided.

As has already been noted, considerations of economy in various directions have led to many changes and improvements in the construction of coke ovens, and it is impossible to describe the numerous forms that these improvements have taken. They seem to have had for their object, first, the more rapid discharging of the ovens; second, the avoidance of the rapid cooling of the oven by watering the coke inside the oven; third, the utilization of the heat in the escaping gases by passing them through flues, where they are burned; and, fourth, the exclusion of air from the coking chamber, the heat necessary for coking being applied from the outside of the oven.

In providing for the more rapid discharging of the oven and the cooling of the coke outside, chiefly for the purpose of greater ease of handling, and to prevent cooling, the oven assumed the rectangular shape, and one of the best of these forms, which may perhaps also be regarded, not as a development of the bee-hive oven, but as a rectangular kiln, closed in at the top, is known as the "old Welsh oven". This is simply a rectangular chamber, 7 by 12 feet, with an arched roof 6 feet high. As generally built, they are set in rows, back to back, with one chimney to each pair to carry off the gases, the length of the oven requiring a greater draught than a vent-hole would supply. A flue from the roof of the oven about one-third way from the back wall leading into the chimney conveys the gases to it. The whole front of this oven is movable, and the coke is drawn by means of a "drag". This drag has various forms, but is essentially a strong piece of flat iron laid across the back of the oven prior to the charging, having attached to it at right angles a rod of iron sufficiently long to extend beyond the front. The protruding end is attached to a chain, operated either by a windlass worked by hand or by a small engine, and the whole mass of coke is drawn at once. In some ovens only the transverse piece of the drag is left in the oven during coking, the rod of iron being inserted after the process is completed through a gutter left in the middle of the floor the end of the rod being shaped something like a fish-hook barb. This rod is pushed in with the bent-up part or, barb flatwise until the end passes under and behind the drag, when the rod is turned, the barb catches on the drag, and the coke is drawn out in one mass. Sometimes the transverse piece or drag is a short length of an ordinary rail; sometimes, also, instead of a single piece of iron attached to the center, which might bend the drag or transverse piece in drawing, two rods, attached near the ends and brought together outside of the oven, are used.

This Welsh oven seems to be preferred in many parts of Great Britain either to the bee-hive oven or to the recent forms of the Belgian oven, as being easily managed and yielding a homogeneous and well-burned coke. Sometimes these rectangular ovens, and also the bee-hive ovens, have bottom flues, through which the escaping gases pass to flues running between the two banks of ovens placed back to back. In this way a portion of the waste heat is utilized for keeping up the heat. In other cases the heat so escaping passes into flues between the two banks of ovens, where the heat is utilized in raising steam for boilers. Such a method is shown in the accompanying drawings of the ovens at the Browney colliery, in the Durham region, England. These ovens will also show the size and general appearance of the Durham bee-hive ovens.

These ovens are in double rows, back to back, as usual, but the flues between are much larger, averaging 6½ feet in height and 3 feet 6 inches in width. To each chimney of 106 feet in height are connected about 100 ovens, an equal number on each side, and the flues and boilers, four in number, are so arranged that the heat can be carried past when cleaning or repairs are requisite, the small connecting flues being built as compact and tight as possible, and thus the remarkable freedom from smoke seems owing to the air-tight and perfect character of the flues, the small amount of surplus air present not cooling the gases to a point below which the hydrocarbons escape imperfectly burnt. This has been tested by admitting a large surplus of air, when smoke was immediately evident.

No coal whatever is used for boiler purposes at these works, and the product of the pit at the colliery where these ovens are situated is drawn from a depth of 100 fathoms, and the water pumped, whereas before this system was adopted 600 tons of coal per fortnight was the amount virtually wasted. At another colliery belonging to the same firm, and where the small coal is valuable for coking purposes, the advantages of the system described are equally evident.

As to the economies in the use of ovens of the Browney type and arrangement, Mr. A. L. Steavenson, in a paper read before the British Iron and Steel Institute (*Journal*, 1877, page 406 *et seq.*), makes the following calculation and statement, which contains many important facts that are not generally known to coke-makers:

In order to ascertain the amount of heat available for evaporative purposes, the first step was to measure the volume and temperature of the gases passing to one pair of boilers from 50 coke ovens at the rate of 230 tons of coal in 84 hours. The temperature was found to be 1,500° F. The volume, measured by taking the velocity of the current in a given length of the flue, was ascertained by introducing sodium at one point and noting the time required to effect a flame, made by putting a little coal into the flue, spectroscopically at another, to be 1,187 feet per minute, which, multiplied into the area of the flue, 24 square feet = 28,488 cubic feet per minute. This exceeds by 4,005 cubic feet the theoretical quantity of the gases, supposing that only just sufficient atmospheric air is admitted to effect the complete combustion of the known weight of material lost in coking 230 tons of coal; and this 4,005 cubic feet represents roughly the unavoidable excess of air used in coking, and the presence of which was evident by the ease with which a piece of charcoal burned when lowered into the flue.

The theoretical quantity above referred to was thus obtained: 230 tons of coal of the following approximate composition—

	Tons.
Oxygen	15.3
Carbon	195.3
Hydrogen	10.3
Nitrogen	2.3
Sulphur	1.4
Ash	5.3
	229.9

yield, on coking, about 60 per cent. of coke, of the following approximate composition:

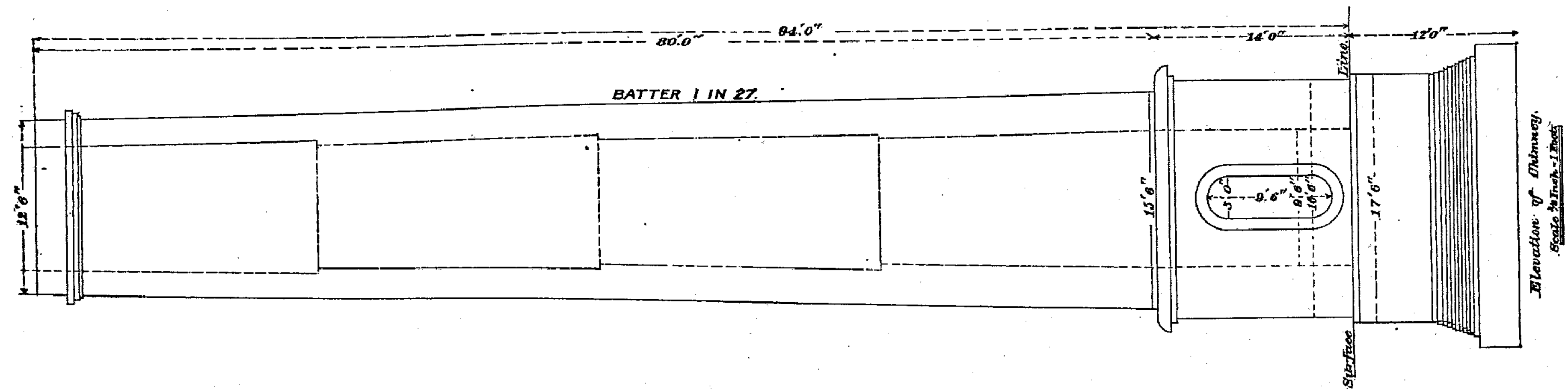
	Tons.
Carbon	132.7
Ash	5.3
	138.0

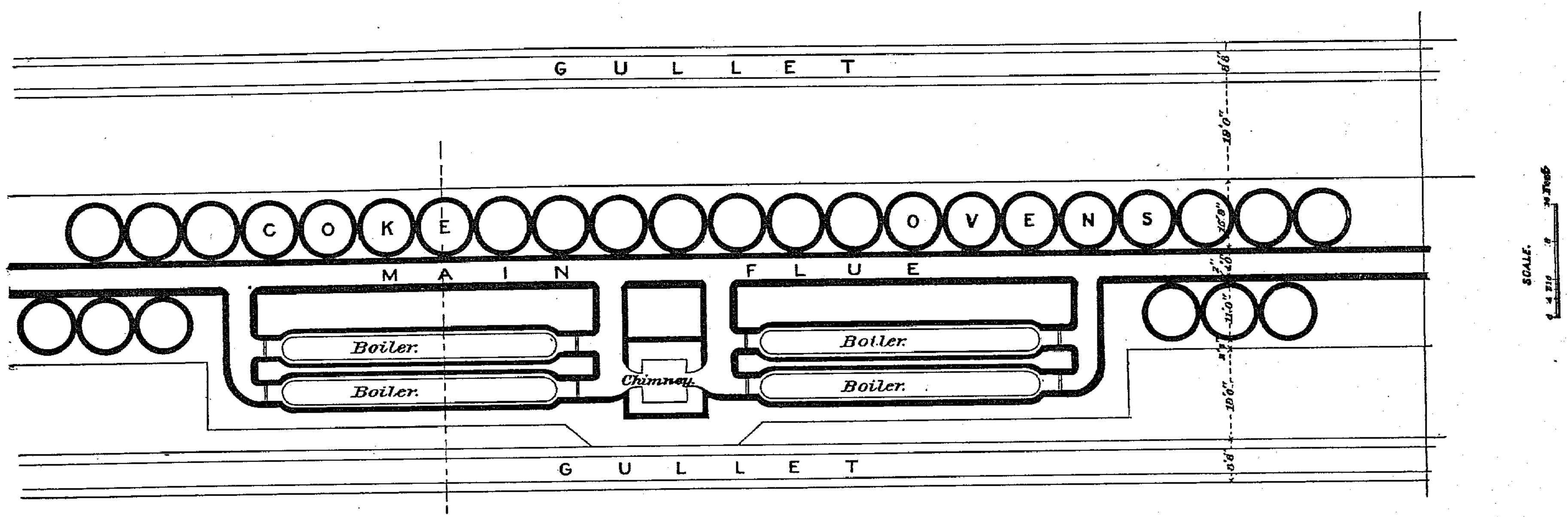
Therefore, the composition and weight of the materials lost in coking are:

	Tons.
Carbon	62.6
Hydrogen	10.3
Nitrogen	2.3
Sulphur	1.4
Oxygen	15.3

BROWNEY COLLIERY.

ARRANGEMENT OF COKE-OVENS, BOILERS, CHIMNEY, &C.





PLAN

Fig. 16.

BROWNEY COLLIERY.

ARRANGEMENT OF COKE-OVENS, BOILERS, CHIMNEY, &C.

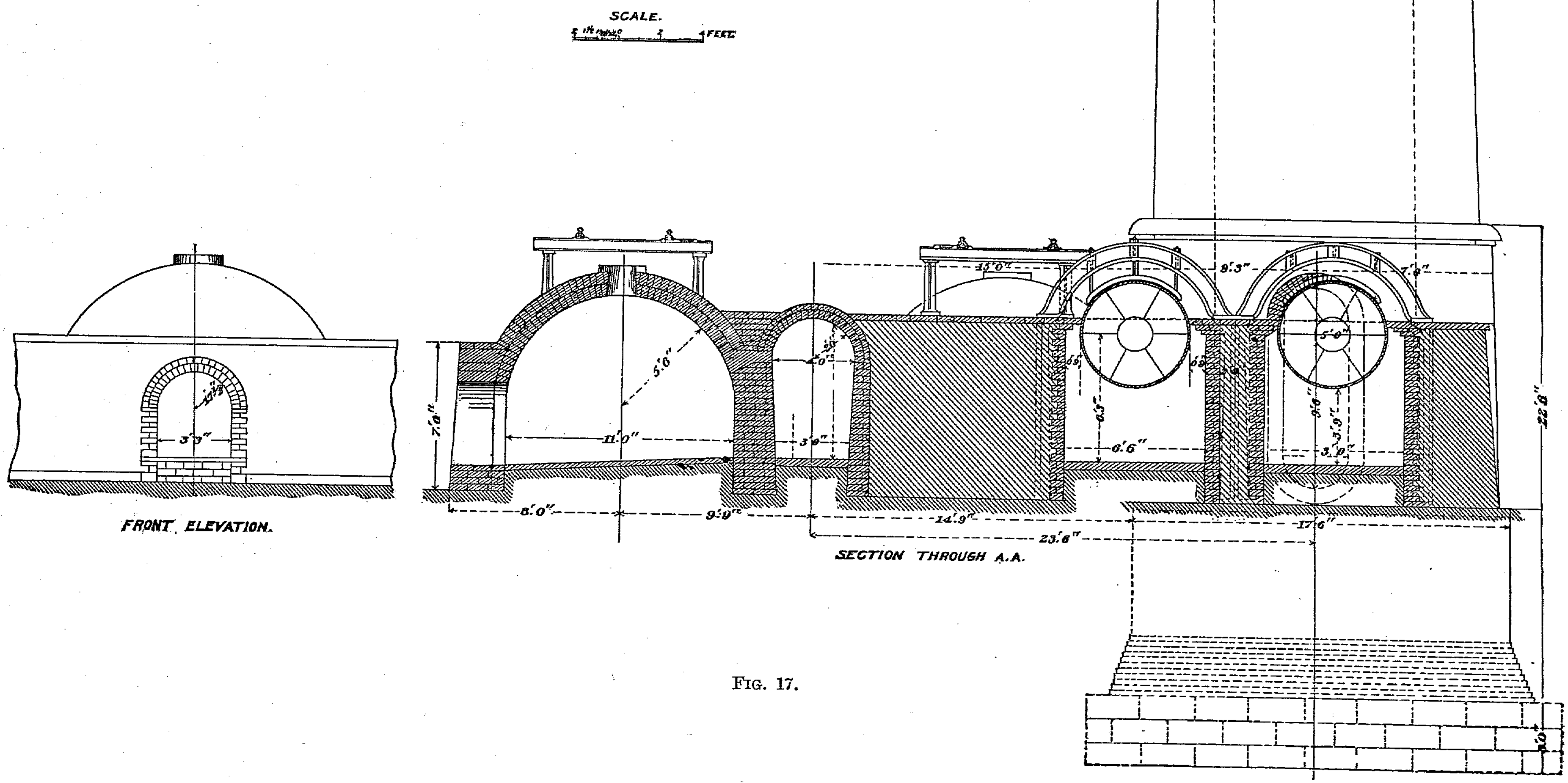


Fig. 17.

To complete the combustion of these into CO_2, H_2O, and SO_2 are required 1,023.4 tons of air, making a total weight of waste gases of 1,115.4 tons, of which 790.3 tons are nitrogen, 229.5 tons carbonic acid, 92.8 tons steam, and 2.8 tons sulphurous acid, which, at a temperature of 1,500° F., will occupy a space of 123,399,000 cubic feet; and since the coking of 230 tons of coal occupies, on an average, 84 hours, we have 24,483 cubic feet per minute, or 4,005 cubic feet less than the observed quantity.

Next, as to the heat commonly wasted: We have 1,115.4 tons of mixed gases, at a temperature of 1,500° F., which, if they could be reduced to the temperature of the atmosphere (say, 60° F.), would have the following heating value in tons of H_2O raised 1° F.:

	Tons. Temperature. Deg. Sp. heat.	Tons H_2O.
N	$790.3 \times 1,440 \times 0.244 =$	277,680
CO_2	$229.5 \times 1,440 \times 0.216 =$	71,384
H_2O	$92.8 \times 1,440 \times 0.475 =$	63,475
SO_2	$2.8 \times 1,440 \times 0.155 =$	625
Tons H_2O		413,164

which is equivalent to evaporating 415 tons of water at 212° F. But, owing to the fact that the temperature of the gases was only reduced 750° F., instead of 1,440° F., the above quantity is reduced to about one-half, or 216.1 tons, evaporated in 84 hours, or 2.6 tons in one hour. This was tested in an actual experiment (on the two boilers supplied with the gases from 50 ovens, coking 230 tons in 84 hours), the quantity evaporated in one hour being 2.4 tons, an approximation quite as close as can be expected.

The total theoretical heat actually developed in the process of coking at the above rate is equivalent to evaporating 17 tons of water per hour, which is thus expended:

	Tons.
Heat utilized by boilers	2.40
Heat escaping in chimney	2.54
Heat lost in radiation from ovens and flues and watering the coke	12.06
Total	17.00

Thus, even in the plan described, but a small percentage of the total heat generated in the ovens is utilized, although if this even was carried out throughout the district of South Durham, where in colliery boilers not more than 6 pounds of water on an average are evaporated per 1 pound of coals, we should have a saving of 1,085,869 tons of coal per annum, or a money value of £271,467. But this by no means represents the total saving to the colliery owners, as foremen are entirely avoided, with the exception of one man on each shift to attend the boilers, so that the total economy which would be effected, were the system generally adopted in the country, would be fully £300,000 per annum.

THE BELGIAN OR FLUE OVEN.

Under the general term "Belgian ovens" is included a number of forms of coke ovens, not all of which, however, are of Belgian invention, which have certain points of resemblance, but all differing from the bee-hive or solid-wall ovens in two, or possibly three, particulars:

First. In the exclusion of air from the coking-chamber, the heat necessary to coking being applied from the outside.

Second. In the utilization of the waste heat and waste gases to facilitate the process of coking.

Third. In the more rapid discharging or drawing of the ovens and in cooling the coke on the outside, thereby saving labor and reducing the loss of heat in drawing and cooling.

Coking in ovens on the Belgian plan is of the nature of distillation in a close vessel or retort, the process proceeding at the same time from the sides, bottom, and top inward toward the center of the mass, the heat for distillation being applied from without and being supplied by the combustion in flues of the waste gases supplemented by the heat retained in the walls. Theoretically this should give all the carbon in the coal; practically there is some waste, but much less than in the bee-hive.

Coking in bee-hive ovens is from the top downward gradually through the mass, the heat necessary to expel the gases being supplied partly by the heat in the walls and the burning of the escaping gases in the coking chamber above the coal and partly at the expense of the carbon of the coal. The coke is cooled inside the bee-hive oven by throwing water upon it before drawing, thereby cooling the oven also. In the Belgian oven, almost without exception, the coke is first drawn out and then cooled, the oven losing but little heat in drawing.

It will be seen, therefore, that, considering only the yield of coal in coke, theoretically the Belgian plan is the better, as it should give more coke to a given weight of coal than the bee-hive oven. The practice is found to agree with the theory, the yield of coal in coke in the Belgian oven being greater than in the bee-hive. Yield, however, is not conclusive as to the economic value of coke, and in deciding which is the better plan, the original cost of the oven and expense for repairs, as well as the character of the coke produced, should be considered. Which is the better oven for making a fuel for blast-furnace purposes is discussed in another place.

To attempt even a brief description of the various forms of the Belgian oven would far exceed the limits of this report. The three that have been selected for description (the Dulait, the Coppée, and the Appolt) are regarded as presenting the most important principles of construction and as being of the most practical importance to the coke manufacturer. These are all flue ovens, but differ in shape and in the location and arrangement of the flues. In all of them the air is excluded as far as possible from the coking chamber, and the volatile matter is expelled from the coal by heat applied outside the walls of the coking chamber, the coke being discharged from the ovens before cooling. It should also be noted that the discharging of these ovens, which is by mechanical means, is facilitated by building them not quite rectangular in form, but with the walls slightly diverging, and, in the case of those which are horizontal, the bottom slightly sloping downward toward the front.

The Dulait ovens are horizontal, long, and narrow, and are heated by the combustion of their volatile products in horizontal flues placed in the sides and bottom, numerous jets of heated air being supplied to the gases in their passage through the flues. They are built in pairs, one oven heating the adjoining one. This division into couples also exists in the Coppée system.

As generally constructed, these ovens are 7 meters (*a*) long, 0.75 meter wide, varying somewhat, however, according to the quality of the coal, and 1.15 meters high to the base of the arch, the arch being 0.10 meter in height. The incline of the bottom of the oven to the front is 0.02 meter to the meter. To prevent waste of heat and the penetration of air the oven is furnished with double doors, the outer one, which is on a plane with the front, being of sheet-iron 0.005 meter thick, and the inner one, which is 0.30 meter from the first, of cast-iron. The space occupied by the coal is thus reduced to 6 meters. The ovens are charged through hoppers closed both at the top and bottom, the lower part being shut by a cast-iron slab cemented with clay in the brick-work, while the upper opening is closed by a cover, the edges of which rest in a channel filled with powdered coal.

The flame from the coking chamber of one oven passes out and descends directly below the bottom of the other member of the pair, where it is divided into four currents, which flow in between the partition walls, and after traversing every flue reach the chimney. To supply the air necessary for the combustion of these products one of the walls of the flues through which the gases pass is built of two rows of hollow bricks, superposed. These bricks have a section of 0.10 by 0.12 meter, and are pierced by a longitudinal hole 0.05 meter in diameter, in such a manner that by their juxtaposition they form two superimposed channels as long as the whole flue. The lower channel is open at the front of the oven and closed at the other extremity, where it rises in order to communicate with the upper parallel channel. This is pierced by holes 0.008 meter in diameter, placed at a distance of 1 decimeter from each other, and opening into the flues in which the combustible gases are circulating. By this arrangement the external air taken in by the draught penetrates into the lower channel, where it becomes heated, and, reaching the upper passage, is projected across the stream divided into innumerable streamlets, which increase the surface of contact, thus effecting perfect combustion and producing the highest possible degree of temperature, so that the gases are in this way fully utilized. As a result, if the coal is of the right quality, the combustible gases are produced in sufficient quantity to secure a complete distillation of the coal and the regular and continuous heating of the whole of the apparatus. This system does away with the necessity for providing openings into the coking chamber for the admittance of air or secures a theoretical absence of draught, limited only by the care with which the clay has been applied to the doors.

The Dulait is a very hot oven, somewhat expensive in its first cost, but requiring only slight repairs, works large charges, and gives a yield nearly equal to the theoretical maximum. It requires, however, constant and careful attention to secure the best results. The charge of coal is from 5,000 to 10,500 pounds, about 7,000 being the average. With the medium or lighter charge the time of coking is 24 to 30 hours, with the heavier 48 hours. The yield as compared with the Smet oven, which it has in some cases superseded, is much greater. Coal that in the Smet oven yielded 71 per cent. yields in the Dulait 79.17 per cent. of large and 1.75 per cent. of small coke, or 80.92 per cent. The cost in Belgium in 1873 for a Dulait oven to produce 5,300 pounds of coke every 24 hours was 2,700 francs. (*b*) In that year there were 1,100 of these ovens in Belgium and 700 in France, Prussia, and Austria.

The Coppée oven is designed for coking only finely-divided coal. It resembles the Dulait oven in being horizontal, long, and narrow, but its side flues are vertical, instead of horizontal, as in the Dulait and Smet ovens, and the methods of supplying air for the combustion of the waste gases, as well as of firing and utilizing the waste heat, are improvements on the Dulait and Smet.

As generally built, the Coppée ovens are in banks or batches of thirty, arranged in groups of two each, one oven of each pair being charged when the contents of the other are half coked, and *vice versa*. Connected with each oven of a pair are a number of vertical flues, or chambers, through which the volatile products from both ovens are conveyed downward to a horizontal flue under one of them. After passing under this oven to its end, the gases return by a similar flue under the other and enter a channel running at right angles to the ovens and under them, passing from this channel either directly into a chimney or carried under boilers and used to generate steam. Air is supplied to these vertical flues in the sides by a smaller vertical flue, one or two to each oven,

a The meter is 39.370$\frac{4}{5}$ inches.

b *Journal of Iron and Steel Institute*, No 2, 1873, page 345, from which the details of cost and yield are taken.

COPPEE'S COKE-OVEN.

COKE-RAM.

ELEVATION.

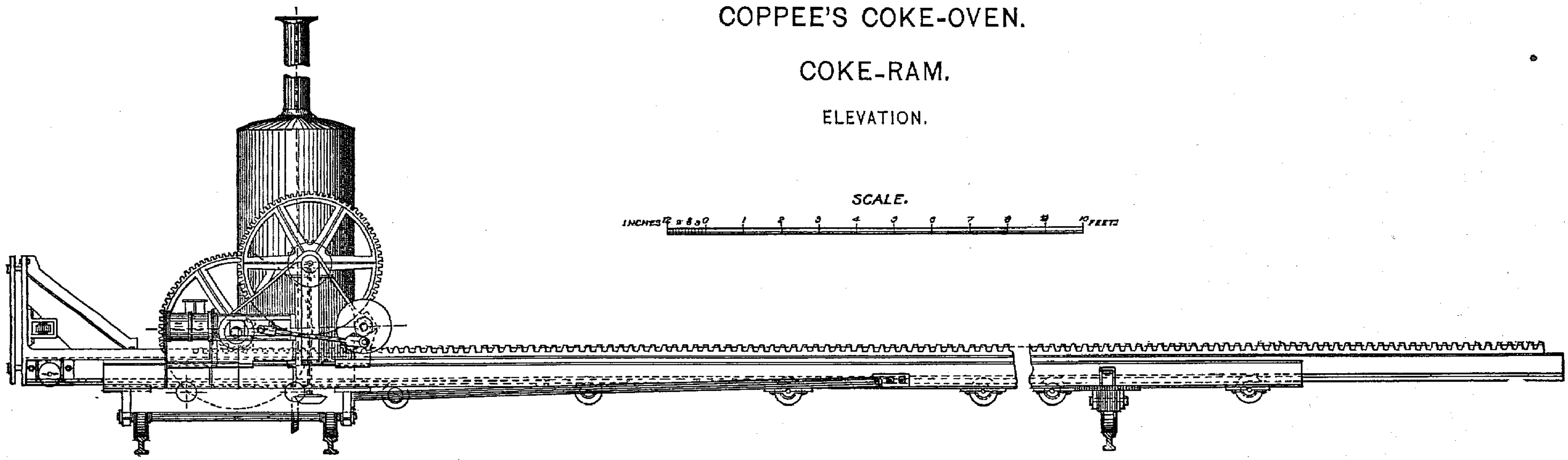


FIG. 18.

COPPEE'S COKE-OVEN.

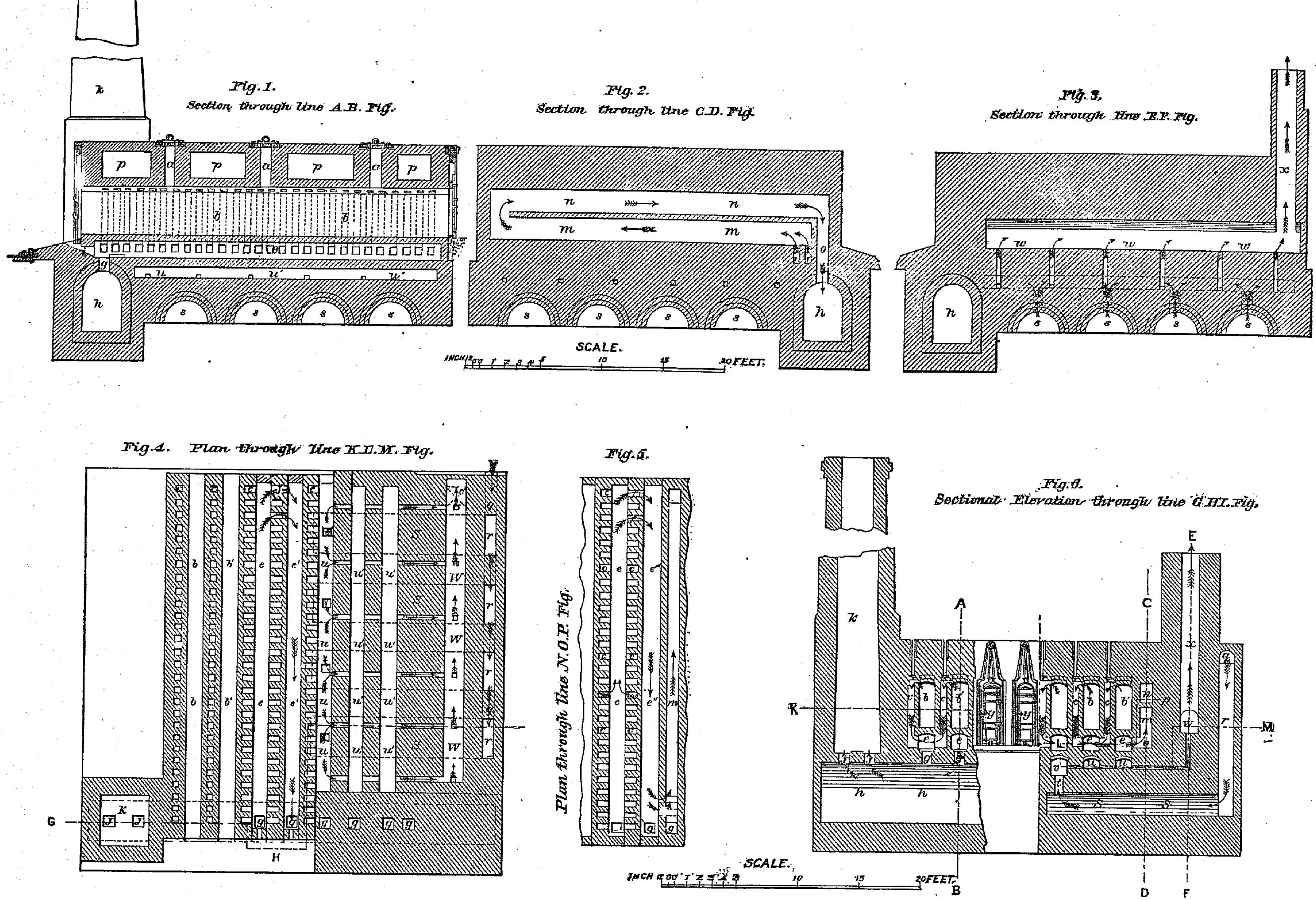


FIG. 19.

APPOLT'S COKE-OVENS.

18 RETORTS.

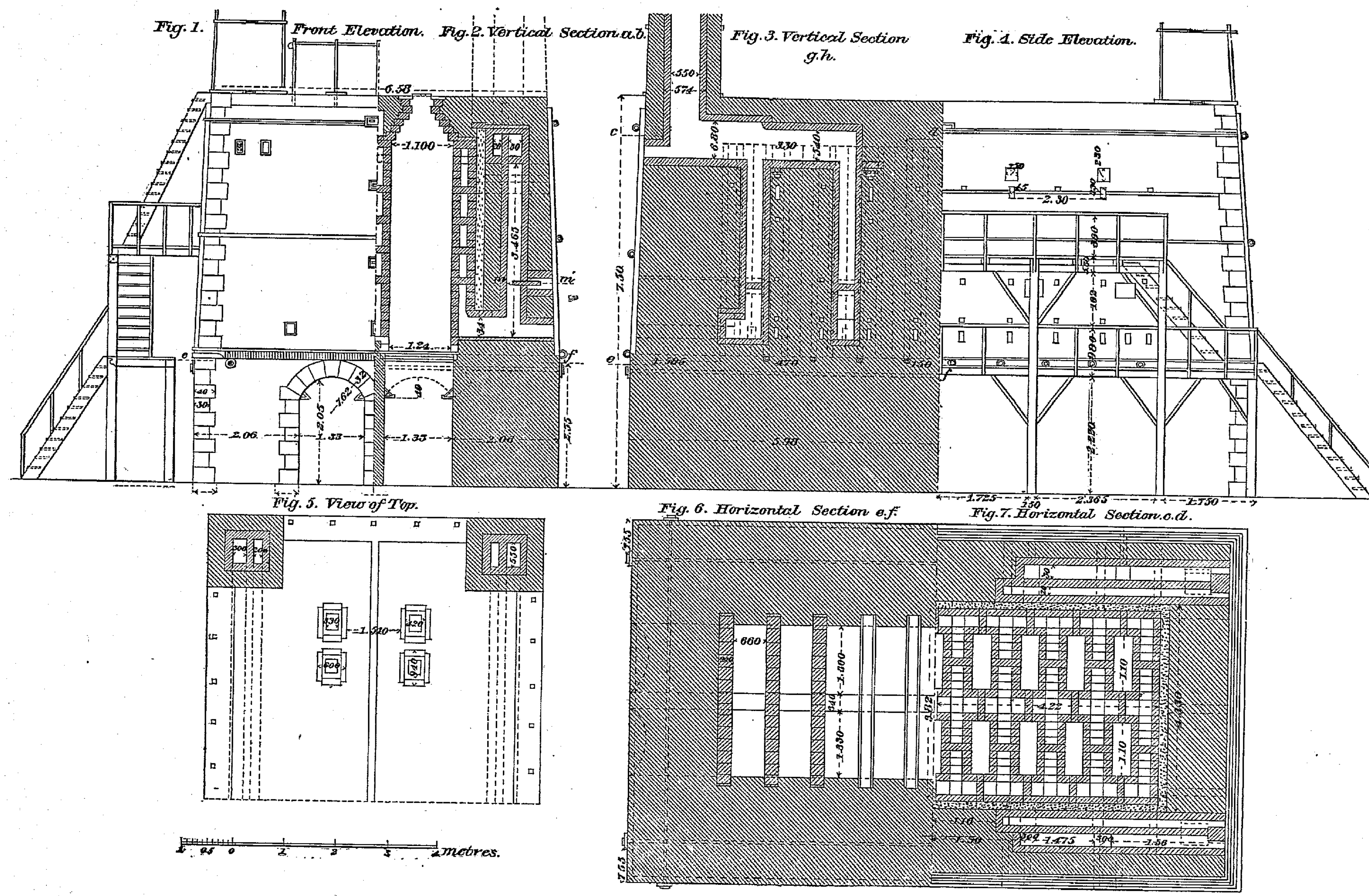


Fig. 20.

connected with the top near the center charging-hole, the air becoming heated while passing through the flue. The ovens are charged from the top through three hoppers, and are drawn by means of a mechanical ram propelled by a cogged driving-wheel, worked by a small portable engine. At each end of the oven are two iron doors moving on hinges and fixed securely in metal frames, the lower 3 feet high, the upper 1 foot. The usual dimensions of the ovens are 26 feet 6 inches long, about 19 inches broad at the back and 17 at the front, and 4 feet high. Ovens of this size are charged every 24 hours; others, arranged to be charged every 48 hours, are 5 feet 7 inches high and 5 feet broad. The thickness of the brick-work between is 13.2 inches. (a)

The accompanying drawing will give an idea of this oven.

The operation of the ram used in discharging the oven by pushing will be readily seen from an inspection of the drawing.

In working the ovens it is necessary first to heat them thoroughly, which is done by lighting fires of coal at the end of every oven close to the doors. When sufficiently hot, the first few charges of coal are in small lumps, the coke produced being of an inferior quality; but in a few days the ovens become so thoroughly hot that crushed coal of the consistency of very coarse meal is used, it being washed, if necessary, to remove impurities.

As has already been stated, one oven of the pair is charged when the coking in the other is about half completed. When ready to charge, the previous charge not having yet been withdrawn, the front and back doors are opened, and the mass of coke pushed out by a ram. The ram is then quickly withdrawn, and the two lower doors are closed. The oven is charged through the three hoppers or openings, and the coal is leveled, by means of rakes, by two men working through the upper doors at each end. The doors are then closed and carefully luted, and carbonization commences immediately. The processes of emptying and refilling the ovens need not occupy more than eight minutes. The coke is quenched immediately upon being withdrawn. Six charges are coked in each oven per week, each charge yielding about 2 tons of coke.

Regarding the yield of the coal in coke it is claimed that within 2 per cent. of the theoretical yield is obtained. Mr. E. Windsor Richards stated to Mr. Percy that at the Ebbw Vale iron works (b) 13,400 tons of coal (containing nearly 20 per cent. of shale) were sent to the washing-machine, and that 8,400 tons of coke were obtained, which is equal to a yield of 62.7 per cent. of the unwashed coal. If the washing process be effective in removing the shale, the yield of the washed coal must be considerably greater. Mr. Richards, however, found as much as 6 per cent. of water in the coke—a point of considerable importance in estimating the yield—the large quantity of water being due to the fact that the coke is quenched outside the oven, and to the want of sufficient care in performing this operation. A series of determinations, recently obtained from Bolckow, Vaughan & Co., limited, of Middlesborough, of the quantity of water in coke made in bee-hive ovens at their Newfield collieries and quenched inside the ovens, gave an average of only 0.8 per cent.

At Ebbw Vale, where there is a bank of these ovens, the work of coking is let to a contractor, who commences by filling the trams from the bin containing the crushed coal; and he finds all the labor for filling the ovens, discharging their contents (inclusive of working the coke-ram), and loading the coke into trams, for one shilling per ton of coke. The additional cost of crushing the coal in a disintegrator must be borne in mind.

In France, in 1878, the cost of making a hundred-weight of coke was about 28 cents, with 20 cents per ton for repairs and incidental expenses.

On page 99 will be found a statement made by Mr. Bainbridge, of the Duke of Norfolk's colliery, regarding the work of the Coppée oven. The advantages claimed for this oven by its inventors are rapidity of coking, largely increased yield, and better coke. It is further recommended by them on the ground that—

> Some qualities of coal which are not sufficiently bituminous to coke in the old oven (or bee-hive) make good coke when burnt in the Coppée ovens; that there is a slight saving of labor by the Coppée system, and that the waste gases of the oven may be utilized for the raising of steam without involving extra expense in the construction.

It may be questioned whether a coal which cannot be coked in a bee-hive oven will make good coke in a Coppée oven. Coke can be made from such inferior coals in the Coppée, but it will be inferior coke. The occasion of the invention of the Belgian oven was to utilize these inferior coking coals, to make it possible to coke them; but it is evident that no oven treatment can supply the lacking chemical elements demanded in making good coke.

In 1873 there were in operation in Belgium 524 Coppée ovens, and 192 were in course of erection. In Prussia 305 were at work and 138 building; in France 186 at work, and in England 30 at work and 30 building. According to Professor Jordan the cost of each oven is from $300 to $350 in France (2,500 to 2,750 francs). (c)

Though not strictly a flue oven, being more of the nature of a retort entirely surrounded by flame, the Appolt oven is very properly treated in connection with the Belgian ovens, as it may be regarded as surrounded by one large flue.

The Appolt oven differs materially from those previously described. It is upright instead of horizontal, and the coke is discharged from the bottom by gravity, instead of being pushed out by a ram. The method of supplying air for the combustion of the waste gas is also theoretically more perfect than in either of the other systems.

---

a A full description, with working drawings of this oven, may be found in Percy's *Metallurgy: Fuel.* London, 1875.

b Percy's *Metallurgy: Fuel,* page 554.

c *Album to Course of Lectures on Metallurgy,* by S. Jordan, C. E. (London, 1878), page 20.

This oven consists of a series of upright rectangular retorts, the longer sides of the rectangle being two or three times the length of the shorter. The retort is also wider at the bottom than at the top, to facilitate the discharge of the coke. These retorts, in groups of 12, 18, or 24, as the case may be, are inclosed in a large rectangular brick chamber, which may be termed the combustion chamber, the retorts being surrounded on all sides by air-spaces, these spaces being in communication, and the walls which form the sides of the retorts connected together by solid blocks of fire-brick. Between the fire-brick walls of the combustion chamber and an outside brick wall is a space filled loosely with some powdered substance, as sand or other bad conductor of heat, which allows a certain degree of expansion and contraction of the fire-brick wall of the combustion chamber within. The combustion chamber for a group of 12 retorts would be about 17 feet long by 11 feet 6 inches wide and 13 feet high. The retorts are about 4 feet long and 1 foot 6 inches wide at the base, and 3 feet 8 inches long and 13 inches wide at the upper part, the walls being about 4¾ inches thick. The distance between the corresponding walls of the neighboring retorts varies from 7¾ to 9¾ inches. (*a*) The ovens are placed in two rows, back to back, the bottoms being provided with cast-iron doors, strengthened by transverse bars of wrought-iron. The partition walls of each chamber, at a distance of from 16 inches to 2 feet from the base, are traversed by two rows of small horizontal openings 5½ inches long and about 3¼ inches high, 9 on each wide and 3 on each narrow side. At the upper part there are three similar openings on each wide side only. Through these openings the volatile products evolved during the coking of the coal pass into the surrounding open spaces of the combustion chamber, where they are burned by atmospheric air admitted through holes in the wide sides of the outer wall of the oven. In the wide side walls are the flues which receive the products of combustion from the flues surrounding the spaces and convey them to the chimneys. There are twelve vertical flues in all, three below and three above in each of these walls.

In operating the oven it is first heated with coal, as in the case of the Coppée oven, until the walls have become red hot. After eight or ten days firing the oven will be found to have attained a temperature of from 1,200° to 1,400° C. (*b*)

In order always to insure an equal degree of heat through the oven, and to simplify the management of the latter by the dampers and air-flues, it is expedient to charge the two series of compartments alternately, the temporary grate and brick lining at the bottom being removed from the compartment which it is proposed to charge. The door is closed and securely fixed, and is then covered with a layer of coke dust about 1 foot thick. This is done to protect the door from heat, to close effectually the bottom of the compartment, and to prevent loss of heat. The charge of coal is now introduced, and a cover is placed over the top, luted with coke dust or clay.

The gases, which are immediately evolved when the coal comes in contact with the red-hot sides of the compartment, pass into the surrounding free spaces, where they are burnt, and so sustain the heat of the oven. An hour afterward a second compartment is charged in like manner, and so in succession until all have been charged. As the amount of gas produced increases during the day with the number of charges, it is necessary to open the dampers, and all that is required to be done during the night is gradually to shut them again in proportion as the evolution of gas decreases. Carbonization being completed at the end of the 24 hours, on the following day the coke is drawn from the first compartment at the same time as the charging took place on the previous day. Immediately afterward the compartment is charged again. The process is thus continued without interruption, the coke being drawn from each compartment 24 hours after it has received a charge of coal. No inconvenience arises from the use of washed coal which still retains moisture. By suitably decreasing the admission of air and the exit of gases from the oven the charging may be omitted on particular days, and yet the heat will continue sufficiently high to enable the charging to be effected on the following day.

The advantages claimed for this oven are as follows: (*c*)

1. The calcination is effected in a close chamber solely by the combustion of gas disengaged from the coal, a condition favorable to a high yield.
2. The heating surface is very considerable, reaching 190 square meters for a charge of 1.5 tons. The comparatively small size of the retort secures a rapid and regular carbonization.
3. The flames from all the compartments uniting in a common chamber, which surrounds them, insure a uniformity of temperature.
4. The vertical position of the compartments, beside the facility of rapid charging and emptying, gives more compactness to the coke, while the arrangement occupies less space.

The following are the inconveniences incident to the system:

1. If the general arrangement does not allow of the coal being led directly out upon the loading platform, lifts must be provided to raise it.
2. Masses sometimes adhere to the sides of the retorts, which have to be broken by bars before the coke can fall.
3. The management of these ovens is not so simple as in some other systems, and when repairs are required for one compartment the whole group has to be stopped.

In the Appolt oven the yield is very nearly the theoretical maximum. At the Blanzy collieries, in France, an oven of 18 compartments is charged with about 24 tons of coal and 3 tons (2,240 pounds) of ashes and dust for covering the

a These dimensions are to be regarded as about the dimensions, they being the equivalents in English feet and inches of the meters of the original paper.

b Percy's *Metallurgy: Fuel*, pages 449, 450.

c *Journal Iron and Steel Institute*, 2, 1873, page 348.

movable bottoms. The operation lasts 24 hours, and produces 17 tons 6 hundred-weight (2,240 pounds) of coke. Taking into consideration the water in the coal (5 per cent.) and in the coke (10 per cent.), the yield would be 68½ per cent., about the yield in a crucible. The cost of the construction of an oven of 18 retorts is about $10,000 (50,000 francs); the cost of coking at a French colliery, including the mixing and breaking of coal and maintenance of oven, amounts to about 43 cents per ton (2 francs 15 centimes).

Dr. Percy, in summing up regarding the Appolt oven, makes the following remarks: (*a*)

This oven differs much in construction from most other coke ovens, and appears completely to fulfill the conditions of a close vessel or retort. Although it certainly is a costly structure, yet according to the inventors the cost in proportion to yield is less than in any other kind of coke oven. Now, it has been previously stated that the non-coking, thick coal of South Staffordshire will cake and produce a solid coherent coke, provided it be rapidly exposed to a high temperature in a perfectly close vessel; and a prodigious amount of the fine slack of such coal has either been wasted or left in the pits because it could not be raised with profit. It may be possible to imitate on a large scale the conditions of the experiment in a crucible and to heat rapidly a large mass of slack to bright redness; but of all the coke ovens known to me, that on the Appolt system seems to be one of the most favorable to the solution of the problem.

Mr. Menelaus, however, informed Dr. Percy (June, 1873) that some years before he saw the Appolt ovens at work near Saarbrück, and that the late M. de Wendel, to whom they belonged, and who was an excellent judge of coke ovens, did not, at least at the time of Mr. Menelaus' visit, see any great merit in Appolt's scheme.

While it thus appears that theoretically the Appolt oven is the nearest to a perfect coke oven, it is not used to the same extent as either the Smet, the Dulait, or the Coppée. It is by far the most expensive to construct, and, as has already been noted, the stoppage of operations to repair one retort necessitates the stoppage of all.

As to which of the many forms of the Belgian oven is the best, but little information has been obtained, as results of comparative trials have in but few instances been made public; indeed, it would be almost impossible to arrive at a general conclusion on this point. It will doubtless be found that one form will give the best results with one kind of coal, while another form will be better adapted to the coking of coal of a different character, but it will always be found true that inferior coal of whatever character will invariably give an inferior coke. Some forms of oven may give a better coke than other forms with the same coal. The true method is to study the character of the coal and adopt the oven that seems best suited to it, having in view economy of operation. At the Cockerill works, at Seraing, Belgium, where a number of Smet ovens had been used for some time, a trial was made of the Dulait, but after careful and thorough experimenting it was abandoned and the preference given to the Smet. On the other hand, at the works of the Société Anonyme des Charbonnages de Marihaye, Belgium, some experiments have been made as to the relative value of the Dulait and the Appolt ovens, with the following result as to the contents of the coke produced:

Constituents.	WASHED.		UNWASHED.
	Treated in the Dulait oven.	Treated in the Appolt oven.	Treated in the Dulait oven.
	Per cent.	*Per cent.*	*Per cent.*
Ash	2.8400	4.4000	9.3400
Water	0.5100	0.4800	0.5800
Carbon	96.6500	95.2300	90.0800
Sulphur	0.0700	0.1016	0.1016
Phosphorus	0.0125	0.0292	0.0292

In England, in the South Wales district, where the Belgian oven has been introduced, and in other parts of England having coals of similar or inferior character, the preference seems to be given to the Coppée ovens, with modifications in some cases, suggested by the experience of the English engineers. While other ovens have been tried, no record has been found of any other form of Belgian oven in use at the present time. The Cox oven, of which the Dulait is in some respects an imitation, and which was at one time used at the Ebbw Vale works, does not seem to meet with continued favor, as at this works, as stated elsewhere, Coppée ovens have been lately built. As noted by Percy in his *Metallurgy*, all of the Belgian ovens, with the exception of the Appolt, seem to be improvements of the old rectangular Welsh oven. In this process of development the Smet, Dulait, and Coppée seem to be successive steps, and the late action of the English coke manufacturers would indicate that with the inferior coals of that country the last step in this development, that is, the Coppée oven, is the best.

SPECIAL ADAPTATIONS OF EACH FORM OF OVEN.

A question of the utmost importance in connection with the manufacture of coke is which is the best oven, and is as difficult to answer as it is important. The form of oven that might be the best, the most economical, and produce the best coke under certain conditions, would not necessarily be the best when these conditions are changed. The oven that would give the most satisfactory results with the coals of Durham, England, or Connellsville, in this country, would not necessarily be the best for the inferior coals of France or Belgium.

a A full description of this oven can be found in Percy's *Metallurgy: Fuel*.

This question as to which is the best form of oven, while it is one contingent on circumstances, is nevertheless answerable as to a given coal. It has been thoroughly investigated in the chief coke-producing countries of the world, and some decided results have been reached as to the best ovens for the coals of the several districts. As there is so great a variety of coals in this country, it may not be unimportant to give these results.

It seems to be quite well settled that with coals similar in character and cost to those of Durham, England, and Connellsville, Pennsylvania, the bee-hive oven, not only as to the character of the coke, but on the score of economy of operation, is the better form. The yield of these coals in coke is no doubt greater in the close distilling ovens on the so-called Belgian plans, where the time of coking and consequent exposure is shorter than it is in the bee-hive ovens, and the coke, in burning, is more or less exposed to the action of highly-heated atmospheric air, but it has been found in blast-furnace practice that this greater yield is more than compensated for by the larger amount necessary to make a ton of iron. This is a somewhat remarkable statement, but it has the sanction of the best authority. Mr. I. Lowthian Bell, the distinguished English manufacturer and writer on blast-furnace phenomena, while acknowledging, in speaking of the Belgian and bee-hive oven, (*a*) that the yield was much greater in the latter, "almost the whole of the fixed carbon being obtained as a coke, the exception being a very minute loss incurred in drawing,"(*b*) nevertheless found the useful effect in the furnaces inferior to that obtained from the coke made in the ordinary oven. In consequence of this all his more recently erected ovens have been constructed upon the old fashion.

Mr. Bell also stated, at a meeting of the British Iron and Steel Institute at Paris in 1878, (*c*) that his firm, among many others, undertook, at considerable expense, the inquiry as to whether it was possible to treat English coal in the same way as coal was treated in France in the manufacture of coke. Both the Knab and the Appolt ovens were tried, and while in both these systems the yield obtained was quite equal to their expectations, they found in practice that whatever advantage was gained in yield was so much lost in the blast-furnace; that the quantity of coal actually consumed in the manufacture of a ton of iron remained pretty much the same in each case. In other words, he found if 30 hundred-weight of coal made 20 hundred-weight of coke in a bee-hive oven and 22½ in an Appolt, that it would require the 22½ hundred-weight of Appolt coke to do the same work in the blast-furnace as the 20 hundred-weight of bee-hive coke. They were compelled, therefore, to go back to the old bee-hive oven, and, as a result, were using a considerably greater quantity of fuel than ought to be the case if the coke made in the better description of ovens had produced an article equal in quality to that produced in the bee-hive oven. He suggested, as one reason for this fact, that the extra coke was consumed in great part in the upper part of the blast-furnace, but another and more simple reason was that as they invariably used a much greater quantity of water in quenching the coke made in the Coppée and Appolt ovens than they did with the bee-hive, a portion of the increased yield was due to the presence of water, and therefore more apparent than real.

There is perhaps another reason for this greater consumption of the coke made in Belgian ovens than of that made in bee-hive ovens. The flued ovens make a denser coke than the bee-hive, and it takes more of it to smelt a ton of pig-iron than of the more cellular coke of the bee-hive. In a word, the difference of consumption may be largely due to the physical condition of the coke; and here it may be pertinent to say that the physical condition of the coke produced with the several ovens is not receiving the attention its importance demands. (*d*)

Mr. A. L. Steavenson, a North of England engineer and writer on coke, went further than Mr. Bell, and claimed that coke was made in bee-hive ovens in the Cleveland district of England that it would be impossible to produce in any of the Belgian ovens. After a study of coke-making in England extending over a period of twenty-five years, he was quite sure that there was not any oven equal to the old-fashioned round oven for producing coke economically for the manufacture of iron. (*e*)

These statements are fully borne out, so far as relates to the cokes made from our Broad Top and Connellsville coals, by the careful and thorough experiments of Mr. John Fulton, mining engineer of the Cambria Iron Company. (*f*) Speaking of the Connellsville coal, Mr. Fulton says: (*g*)

> The best quality of Connellsville coke treated in the Belgian ovens of the Cambria Iron Company produced a coke of very objectionable density, especially in the bottom and middle of the charge.

A direct test to determine the relative calorific values of cokes made in bee-hive and Gobeit ovens, using the same quality of coal in each kind, was made at the furnaces of the Kemble Coal and Iron Company, in the Broad Top coal region, Pennsylvania, by William Lauder, the general superintendent. The furnace in which

---

a *Chemical Phenomena of Iron Smelting*, I. Lowthian Bell, London, 1872, pages 314, 315.

b *Transactions Institute of Mechanical Engineers*, 1871.

c *Journal of the Iron and Steel Institute*, No. 2, 1878, pages 346, 347.

d Mr. Fulton suggests that the denser coke may not be as vigorous a fuel as the more cellular, or, in other words, that as many tons of pig-iron could not be made in a week in a furnace using the denser coke as in one using the cellular. A comparison between the makes of furnaces using Connellsville coke and those using anthracite, which is practically a dense coke, will illustrate what is meant by a "vigorous fuel".

e *Journal of the Iron and Steel Institute*, page 354.

f See *Second Geological Survey of Pennsylvania*, Report G (Harrisburg, 1878), pages 235 *et seq.* Also Report L, pages 117 *et seq.*

g Report G, page 248.

the tests were made is 14 by 60 feet, with modern blowing machinery and hot-blast oven. The ores are from the Clinton group (No. V), well known as the Juniata fossil ore, containing 30± per cent. of metallic iron. The increased density of coke made in the Gobeit was very manifest. It was found that with careful management in both trials it required 2,300 pounds of Gobeit coke to carry the same furnace burden as 1,900 pounds of bee-hive coke. Mr. Lauder confesses his surprise at the results. While this coke was in the furnace it took 5,196 pounds to 1 ton of pig-iron; with the bee-hive coke 4,156 pounds for the same work. The loss, per ton of pig-iron made, is 1,040 pounds of coke, or 20 per cent. If the furnace makes 250 tons a week, the loss will be 115½ tons of coke, at $2 25= $259 87 per week.

This testimony in favor of the use of the bee-hive oven for coking the coals of western Pennsylvania is further strengthened by the action of certain coke manufacturers in that region, who, after having thoroughly tried certain forms of the Belgian oven, have, on increasing their coke-plant, built nothing but bee-hive ovens.

It may be assumed that, for coking, the character of coals, of which the Durham and the Connellsville may be taken as the type, and having in consideration the fact that the use to which coke is most largely put is in blast-furnace work, the bee-hive oven is the best. It may be possible that in the development of the iron business and the increased demand for coke, coupled with the exhaustion of coal-beds and the necessity of going deeper and further into the hills for coal; in a word, with the increased cost of the character of coal which is so admirably adapted to the manufacture of coke, some modification of the bee-hive oven that will give a similar character of coke without so great waste will be adopted; but we are speaking, of course, of the present and the present conditions.

In noting these results and opinions it is scarcely necessary to state that in the experiments recorded all forms of the so-called Belgian oven have not been tested and the results compared with those obtained in the bee-hive ovens. It is fair to presume, however, that tests made by such eminent engineers as Messrs. Bell and Steavenson in England and Mr. Fulton in this country would be carefully and thoroughly made, and that the Belgian oven selected for trial would be regarded as the best form for the coal used with which they were acquainted at the time the test was made.

It should also be noted that in these statements the coke is considered only as to its value as a blast-furnace fuel; the economy of coking is not taken into account.

It is also fair to state that the experience of Messrs. Laughlin & Co., of the Eliza furnaces at Pittsburgh, is favorable to the use of the Belgian ovens. The oven they use is the old François oven, improved by Mr. Henry Laughlin, and are 22 feet long, 18 inches wide, and 5 feet high, flues being arranged vertically in the side walls, which are 13 inches thick. Mr. Laughlin states that he has used Connellsville coal in these ovens with very good results, the time of coking being very much shorter and the coke produced equally as good as that made from the same coal in bee-hive ovens, but the yield was greater. They also use at times a mixture of Connellsville coal and the fine slack from the Monongahela river, but for the most part use the latter alone after careful washing, it making a lighter and more porous coke than the Connellsville coal. They get every 24 hours about 2,000 pounds of coke from each oven. A remarkable difference between their practice and that ordinarily used with the Belgian oven is that the coke is watered in the oven as in the bee-hive and is pushed out cold, and it may be possible that the better quality of the coke from these Belgian ovens is in part due to this watering inside.

So far this question of the relative value of different forms of ovens has been considered only with reference to the coking of coals similar to those of Durham, England, and of Connellsville, in this country, and it seems well established that with these coals the bee-hive oven has so far given the best results; but all coals are not of the character of these, nor are they so easily coked. Mr. E. Windsor Richards, of Blockow, Vaughan & Co.'s steel works at Eston, England, very aptly remarked of the Durham coal: "It would be very difficult not to make good coke with it;" (*a*) and a similar statement may be made of the Connellsville coal. The question arises, regarding those coals that in the bee-hive oven have made inferior coke, or, as they are termed, the "inferior coking coals": Are any better results obtained with these coals in the Belgian oven than in the bee-hive or similar forms?

The evidence seems conclusive that, with certain inferior coals, the Belgian oven produces a better coke than the ovens of which the bee-hive is the type. In a word, certain inferior coking coals can be coked in the Coppée or some other form of Belgian oven which cannot be coked in the bee-hive. Many coals do not contain sufficient hydrogenous matter to thoroughly ignite and agglutinate in the bee-hive; they lack the pitchy matter to supply heat and bind the coal together in coking. In the Belgian oven, however, by reason of the greater heat, these coals catch more readily, and, the process being quicker, they bind together better. In many cases where the Belgian oven is used on these dry coals it is found advisable to mix them with coals containing more "pitch". This has been done at the works of the Cambria Iron Company with their Belgian ovens. At the same time, however, it seems to be a fact that the invention of the Belgian oven was the result of necessity, not of advanced scientific method. The European coals for which this oven was designed were very dry material for coke—could not well be "stuck" together in the old circular oven, and hence a costly appliance had to be used to make it possible to use these inferior coals in coke-making.

Up to 1852 coke was made in Belgium in bee-hive ovens, or in others with solid walls, somewhat similar in

a Journal Iron and Steel Institute, No. 2, 1878, page 348.

construction to the bee-hive. At this time the cost of the bituminous coal used increased to such a figure that it was necessary to use inferior coal for coking or to abandon iron-making. Out of this have grown the many forms of the so-called Belgian oven, the principles of which are described in the chapter treating of ovens.

The fact that the old forms of oven have been entirely abandoned in Belgium is the most convincing evidence that for the Belgian coals they are not the best form. The testimony as to which of the many forms of the Belgian is the best is not conclusive, but it seems generally conceded in Belgium, as the result of careful and long-continued experiments and comparisons, that almost any form of the oven is better than the bee-hive for their coal.

A similar statement is true of France. The French coals chiefly used for coking are not typical coking coals, being dry and quite impure, and consequently high in ash. In that country the coke is generally made in the Coppée or Appolt forms of the Belgian oven. In the discussion of Professor Jordan's paper, which has been before referred to, Mr. Windsor Richards stated that his impression was that without the Coppée or Appolt oven coke-making in France would be impossible. (*a*) In discussing this further, Professor Jordan said: (*b*)

The improved coke ovens, Belgian or Appolt system, yield with the same quantity of coal a higher percentage of coke than the old bee-hive ovens, because there was a smaller loss by combustion in the oven, and also because the proportion of small coke or cinders was smaller, as was also the cost of working. It is a fact universally known to be true by the French and Belgian coke manufacturers that the cost of production of a ton of coke in a Belgian or an Appolt oven is smaller than in a bee-hive oven. There is less coal and less labor required. For the blast-furnace process, coke must be considered as to its percentage of ash, and as to its porosity and friability. A percentage of ash can be obtained as low in the improved coke ovens as in the old form; indeed, by using the same coal, a purer coke is produced in the new ovens, since the yield is higher. As to the porosity and friability, which depend above all on the quality and the physical state of the coal used, and also on the thickness of the layer of coal in the coke oven, the French manufacturers certainly obtain in their improved ovens coke as dense and as hard, indeed, perhaps more dense and more hard, than in the old bee-hive ovens.(*c*) Therefore, Professor Jordan said he could not find an explanation of the fact recorded by Mr. Bell. He was not aware of any trial made by iron-masters for comparing the two kinds of coke for blast-furnace use, but all the blast-furnaces in the Loire district had formerly used coke made in bee-hive ovens, and actually now used coke manufactured in improved ovens, and they had never had any disadvantage resulting from the change.

Professor Jordan, referring to Mr. Richards' remarks, agreed with them. The only coals to be got by French iron-masters were generally inferior to those of Durham for coke-making. In old times, when the consumption of coke was not very extensive in France, it was manufactured from caking coals in bee-hive ovens; this, for example, was the case with the Loire coal-field. Now, however, that the wants of the iron trade have increased other kinds of coal are largely employed.

Professor Jordan believed (*d*) that, in spite of the unfavorable results referred to by Mr. Bell, the Durham coke-makers would adopt in due time the improved systems of coke ovens used in France, Belgium, and Westphalia. The failures reported by Mr. Bell had also been incurred by German manufacturers in the Loire coal-field, where formerly coke was made only from caking coal in bee-hive ovens. There the improved systems had been introduced in practice later and more slowly than elsewhere, because the first trials had been made with systems of ovens which, though having merits for other qualities of coal, were somewhat inappropriate for that used. He ventured to say that the same had perhaps happened to Mr. Bell. It should always be remembered that when making trials with coke ovens of the Smet, Coppée, Appolt, or other class failure might result instead of success, in consequence of a difference of some inches, more or less, in the breadth of the oven or the dimensions of a flue, or probably of some units too much or too little in the percentage of humidity of the coals prepared for carbonization. These improved ovens required also more attention and care than the old ones.

In Westphalia, though the coal is superior to the French for coking, being somewhat similar to the Welsh steam-coal, it has been found that better results are secured by the use of the Belgian ovens than by the old style of bee-hive ovens. The details and experience in the use of these ovens in this part of Germany have not been procured, but the relative number is conclusive evidence as to which form is deemed best. Of the 5,300 ovens reported in the Westphalia district, the far greater number are of the Coppée system. Dr. Gustav Natorp, in his paper read before the British Iron and Steel Institute, says:

Although it is the opinion of some engineers that the coke produced in the bee-hive ovens is superior in many respects to that of the Coppée ovens, the former have, nevertheless, not been generally adopted, since a coke can be far more cheaply produced in the Coppée ovens, which answers all the requirements, not alone of our native iron industry, but of that of Belgium, Luxembourg, and France as well.

Even in England itself there is strong evidence of the superiority of the Belgian ovens of the Coppée system for the manufacture of coke from certain of the British coals, especially those of South Wales.

Mr. Richard Meade, in his recent work on *The Coal and Iron Industries of the United Kingdom*, page 201, says:

The coke manufactured in the ordinary way in South Wales, although exceedingly hard and dense, does not appear to have attained all the economical results possible. Experience has shown that the carbonization of the coal is not complete, the long, deep fissures in the coke thus manufactured exhibiting, on examination, a considerable amount of dark carbonaceous matter not carbonized.

---

a Journal Iron and Steel Institute, No. 2, 1875, page 348.

b Idem, pages 349, 350.

c A confusion of denseness and hardness of coke may exist in some of these cases. Dense coke is not desirable; hard coke is. As is explained under "Properties and composition of coke", a hard coke is one in which the cell-walls in the fuel are hard; a dense coke is one in which the number of cells in the coke is small.

d Journal Iron and Steel Institute, No. 2, 1878, pages 352, 353.

At the Ebbw Vale iron works, in South Wales, 60 ovens were constructed on the Coppée system in 1874, and so successful has been their use with the coals at these works that 60 more were erected in 1880. In the same year the Dowlais iron works decided to erect two blocks of 72 ovens each, and it was also reported that the Barrow Hematite Company had decided to make a trial of their coal, which is a very much poorer coking coal than even the Welsh, in these ovens. In Pembrokeshire, where the coal is not at all caking, good coke was obtained in the Coppée oven with the mixture of 50 per cent. of anthracite dust with bituminous coal and some pitch.

At the Dowlais works the first block of 72 ovens on this system was put into full operation early in 1881, at which time they produced 1,000 tons a week of excellent coke from a coal containing but in a slight degree those qualities that are considered necessary for coke-making. The success of these ovens at Dowlais led to the erection, in 1881, of a block of 72 similar ovens by the Rhymney Iron Company. (*a*)

From what has been said we think it is evident that while for coals similar to those of Durham, England, and Connellsville, Pennsylvania, under the present conditions as to prices and demand, the bee-hive oven is the best form for coking. We think it is also evident that for other coals, which may be termed inferior coking coals, similar to those of France, Belgium, Westphalia, those mentioned in South Wales, and the Cumberland district, the Belgian system, or some form of the Belgian system, is better than the bee-hive or a solid-walled oven.

As to the relative cost and results of the two systems, many comparisons have been instituted. Mr. Emerson Bainbridge, who has gone very fully into the respective merits of the bee-hive and Coppée systems of coke manufacture, has prepared the following summary of the chief points of comparison, which exhibit some interesting features: (*b*)

	Bee-hive.	Coppée.
First cost per 2 tons of coke per day	£119 7*s*.	£100.
Time of burning	48 to 120 hours.	24 hours.
Area per ton of coke daily	1,218 square feet	234 square feet.
Per cent. of yield	45 per cent.	59 per cent.
Outside cooling-surface per 2 tons	1,002 square feet	175 square feet.
Time in emptying and refilling	69 minutes	8 minutes.
Units of heat in waste gases per oven	960.710	1,401.584.
Labor charge per ton	1*s*. 3*d*.	11*d*.

Mr. Fulton, in discussing this point, says: (*c*)

The relative cost of making coke in each kind of oven is hereby given, with original cost of ovens and annual cost of repairs. The estimate contemplates banks of ovens to produce 100 tons of coke per day, or 30,000 tons per year. Coal at $1 per ton delivered at ovens.

BEE-HIVE OVENS.

80 ovens, at $200	$16,000
Interest on investment, 10 per cent. per annum	1,600
Annual repairs and renewals, at $10	800

Then $\frac{\$2,400}{30,000\text{ tons.}}$ = 8 cents per ton of coke.

COST OF COAL AND COKING.

1.60 tons of coal, at $1 per ton	$1 60
Labor at ovens, charging and drawing	27
Interest on cost of ovens and annual repairs	8
Coal, $1 60; coking, etc., 35 cents	1 95

BELGIAN OVENS.

65 ovens		$45,200
Engine for pushing coke out of ovens		3,000
Annual repairs to engine		50
Tracks for engine		300
Annual repairs to ovens		310
Annual interest on investment ($48,800), at 10 per cent.	4,880	

Then $4,880+$310+$50 = $\frac{\$5,240}{30,000\text{ tons.}}$ = 17½ cents, nearly.

a Mr. Edward P. Martin, manager of the Dowlais iron works, writes me under date of November 23, 1882:

With regard to the question of yield of coke, we consider that the yield in the Coppée oven is better than in ordinary ovens; how much, it is difficult to say, as we do not weigh the products. With regard to the question of cost, taking into consideration the greater output per oven, we do not think that the cost per oven per ton of coke made is in excess of ovens built on the ordinary plan. The time of coking with us is 24 hours. The coke, if we use a fair quality of coal, is good and hard, but it has not that silvery appearance so taking to the eye which we get from good coal from ordinary ovens. Chemically and mechanically there is no difference in the quality, as far as we are able to judge, on the blast-furnaces. The cost per oven in this country is about £100 each, including roads, foundations, etc. The labor expense is less than in operating ordinary ovens. We have 72 ovens, and these 72 ovens burn out about 1,000 tons per week, or 14 tons per oven per week.

b Ure's *Dictionary of Arts, Manufactures, and Mines*, vol. iv, page 262.

c *Second Geological Survey of Pennsylvania*, Report G, pages 249, 250.

COST OF COAL AND COKING.

Coal, 1.42 tons, at $1 per ton	$1 42
Labor at ovens, charging, luting, pushing, etc	23½
Interest on cost of ovens and annual repairs	17½
Coal, $1 42; coking, etc., 41 cents	1 83

The Belgian plant of ovens is the more costly in construction, but less expensive in repairs and coking.

The economy in this class of ovens consists in the saving in coal to make 1 ton of coke, the saving in the work of discharging the coke out of ovens, and in their annual repairs.

The bee-hive oven is less costly in construction, but more expensive in annual repairs. Regarding the two systems in the aspect of absolute economy, embracing the interest of invested capital in their construction with annual repairs of each, and without any reference to the value of the coke made by each kind of oven, the Belgian exhibits an economy of 12 cents per ton of coke in its favor.

Mr. Fulton sums up the whole question as follows: (*a*)

The inquiry as to the best oven will be confined to a comparison of the bee-hive and Belgian, the Appolt being regarded as planned for peculiar cases which are not embraced in the limits of the present investigation.

The advantages of the bee-hive are mainly as follows: first, it produces from the coal the best possible physical structure of coke; second, it yields a uniform quality of coke; third, its coke watered out in the oven is produced in the driest condition; fourth, in rabbling it out it is separated into diminutive pieces; and fifth, the operation of coking in it is simple, and the cost of oven and repairs moderate.

The Belgian or François oven has its advantages: first, it produces a uniform quality of coke; and second, it is the most economical method of coking.

Its disadvantages consist mainly with the ordinary coking coals in making a dense coke. It requires skill in its coking operations; it requires its coke to be quenched outside in a clumsy manner, producing a damp fuel; its cost is large, but its repairs moderate.

It is only especially adapted to the family of coals demanding pressure in coking, to prevent too inflated a physical structure, and to the peculiar cases hitherto noticed consisting of coals holding a minimum of volatile matter and requiring washing.

Perhaps at present it is possible to secure coke made in the bee-hive ovens from the excellent coals of the Allegheny mountains at such rates as would not justify the attempt to coke what might be termed the "inferior coking coals" of the states of the Mississippi and Ohio valleys outside of the Allegheny region, but in the near future the question of the coking of these inferior coals will be one of considerable moment, and it is for this reason that it has been discussed at length here.

THE UTILIZATION OF WASTE PRODUCTS.

The enormous waste in coking has been a subject of earnest consideration on the part of coke-makers for many years, and various methods have been suggested and tried for saving this waste. The waste heat has been partially utilized—

First, by changes in the construction of the ovens, building them in banks or blocks, and by the use of flues in their sides and bottoms.

Second, by carrying the heated gases under boilers and utilizing them for raising steam.

This waste of heat, however, is a mere bagatelle to the waste of the by-products that pass off during the distillation of coal. In the manufacture of gas one of the principal sources of income is the sale of tar and ammoniacal liquors, and the amount and the value of these by-products in gas-making would scarcely be credited did it not have the sanction of such high authority. (*b*)

The color industry utilizes practically all the benzine, a large proportion of the solvent naphtha, all the anthracene, and a portion of the naphthaline resulting from the distillation of coal-tar, and the value of the coloring matter thus produced was given as £3,350,000. The present production of 1,000,000 tons of liquor yields 95,000 tons of sulphate of ammonia, which, taken at £20 10*s*. a ton, represents an annual value of £1,947,500. The total annual value of the by-products of the gas-works of the United Kingdom may therefore be estimated as follows:

Coloring matter	
Sulphate of ammonia	£3,350,000
Pitch (325,000 gallons)	1,947,500
Creosote (25,000,000 gallons)	365,000
Crude carbolic acid (1,000,000 gallons)	208,000
Gas coke, 4,000,000 tons (after allowing 2,000,000 tons consumption in working the retorts) at 12*s*	100,000
Total	2,400,000
	8,370,500

Taking the coal used, 9,000,000 tons, at 12*s*., as equal to £5,400,000, it follows that the by-products exceed in value the coal used by very nearly £3,000,000. In using raw coal for heating purposes these valuable products are absolutely lost.

a *Second Geological Survey of Pennsylvania*, Report G, pages 248, 249.

b Dr. Siemens, in his address as president before the British Association at Southampton, August, 1882, estimates that 9,000,000 tons of coal were used annually in the gas-works of the United Kingdom, producing 500,000 tons of tar, 1,000,000 tons of ammoniacal liquors, and 120,000 tons of sulphur.

It is evident from this that the value of these products wasted in coke-making, which is essentially the same as gas-making, is enormous. On the basis of the above estimate, assuming a consumption of 7,000,000 tons of coke annually in the blast-furnaces of Great Britain, there would be a loss of by-products to the value of nearly £4,643,333⅓. Dr. Angus Smith, the English inspector under the alkali acts, estimates that 20 pounds of ammonia are given off in the combustion of every ton of coal manufactured into coke. This would equal 27,524 net tons of ammonia as the product of coke-making in the United States in the census year. It is well known that there exists an almost unlimited demand for sulphate of ammonia for agricultural purposes, all the more so as the natural manures, such as guano, saltpeter, etc., are getting scarcer and scarcer, or deteriorating with respect to the quantity of nitrogen they contain. Latterly the ammoniacal liquor has also been used in the manufacture of soda under the Solvay patents.

A number of attempts have been made in England, extending through a series of years, to utilize these by-products, and ovens have been built and appliances attached to the ordinary bee-hive ovens for this purpose, but with very little success until recently. While no difficulty was experienced in collecting these waste products in the earlier trials, the coke was inferior, and there was some trouble in maintaining the necessary flues. Messrs. Pease & Partners, in the north of England, have quite recently started a block of 25 ovens, (*a*) to which they have applied the Carvès plan, of whose success they speak very favorably. This plan has reached its best development at Bessèges, France, at the works of the Terrenoire Company, though it is in successful operation at other places on the continent of Europe. On pages 102 and 103 will be found drawings of these ovens as modified by Mr. Henry Simon, with a full statement of the working of the ovens and the results attained. (*b*)

In this oven the coal is rapidly carbonized by subjecting a comparatively thin layer to a high temperature in a closed and retort-like vessel, the volatile products being burned around the outside of this vessel after they are deprived of the tar and ammoniacal liquor.

Each oven is in the form of a long, high, narrow chamber of brick-work—a Belgian oven in fact—a number being built side by side, with partition walls between them sufficiently thick to contain horizontal flues. Flues are also formed under the floor of each oven, and at one end of these is a small fireplace, consisting of a fire-grate and ash-pit, with suitable door, the fire-door having fitted above it a nozzle, through which gas produced from the coking is admitted to form a flame over some fuel burning on the grate. Only a very trifling amount of such fuel, consisting exclusively of the small refuse coke, is used here, its function being really more that of igniting the gas than that of giving off heat. These grates when in regular work are not charged with fuel more than twice every twenty-four hours.

The products of combustion pass from the fireplace along a flue under the oven floor to the end farthest from the fire, and return along another flue under the floor to the fire end. They then ascend by a flue in the partition wall to the uppermost of several horizontal flues formed therein, and descend in a zigzag direction along these flues, finally passing into a horizontal channel leading to a chimney. Thus the coke oven is heated not only at the bottom in the usual manner, but also evenly at the sides, and the coal with which it is charged becomes rapidly and completely coked. No air is allowed to enter the ovens. These ovens are fed with coal through openings in the roof, over which coal-trucks are run on rails; and the coal is evenly distributed by rakes introduced at end openings provided with doors faced with refractory material, which doors are closed and kept tightly luted while the oven is in operation. The feed-holes in the roof are also provided with covers. Through the middle of the roof rises a gas-pipe provided with a hydraulic valve, which closes the passage by a lip projecting down from it into an annular cavity surrounding its seating, in which it is immersed in a quantity of tar and ammoniacal liquor lodged there during previous distillations. The volatile products of the coal-distillation rise by the gas-pipe and are led through a range of pipes kept cool by external wetting, so that the tar and ammoniacal liquor become condensed and separated from the combustible gas.

The quantity of these by-products depends, of course, mostly on the nature of the coal used, as the richer the coal is in bitumen or gas the greater the value of the by-products.

Much also depends on the proper conduct of the temperature at the different stages of the coking process, for it is quite possible to obtain even from the same coal different proportions, quantities, and qualities both of the coke and the by-products. Practical experience must in each case determine what is best adapted to local requirements and circumstances.

The cooling-pipes are conveniently arranged in pyramidal form, surmounted by a water-pipe having numerous holes, so that a shower of water descending on the uppermost and the outermost is scattered over all their surfaces.

The gas, when thus separated from the condensed materials, is further passed through scrubbers or vessels containing coke moistened by the ammoniacal liquor, which, on being repeatedly used, becomes stronger and stronger, until it reaches saturation, when it may be run off into reservoirs, to be treated in the ordinary way for

a Now (December, 1882) building additional ovens.

b Partly from a paper read before the British Iron and Steel Institute by Mr. Henry Simon, and partly from Dr. Angus Smith's fourteenth and fifteenth reports under the alkali acts.

the preparation of ammoniacal compounds, or sold in its crude state for the manufacture of soda. All valuable by-products having thus been withdrawn from the gas, it is led by pipes to the nozzles at the fireplaces under the sole of the ovens, where it is burnt.

SIEMENS-CARVÈS OVEN.

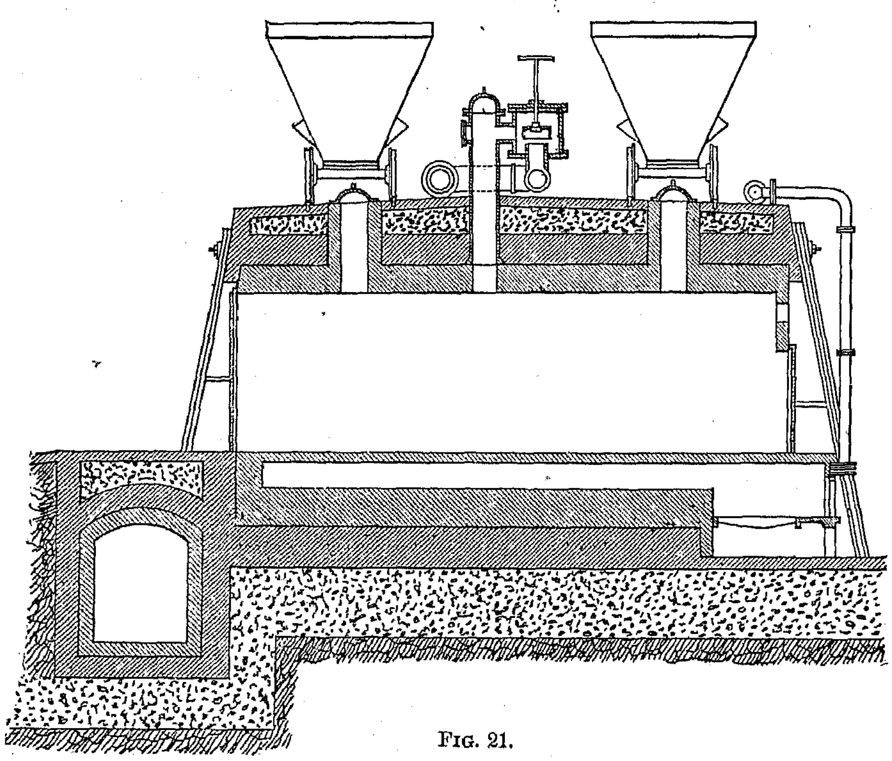


FIG. 21.

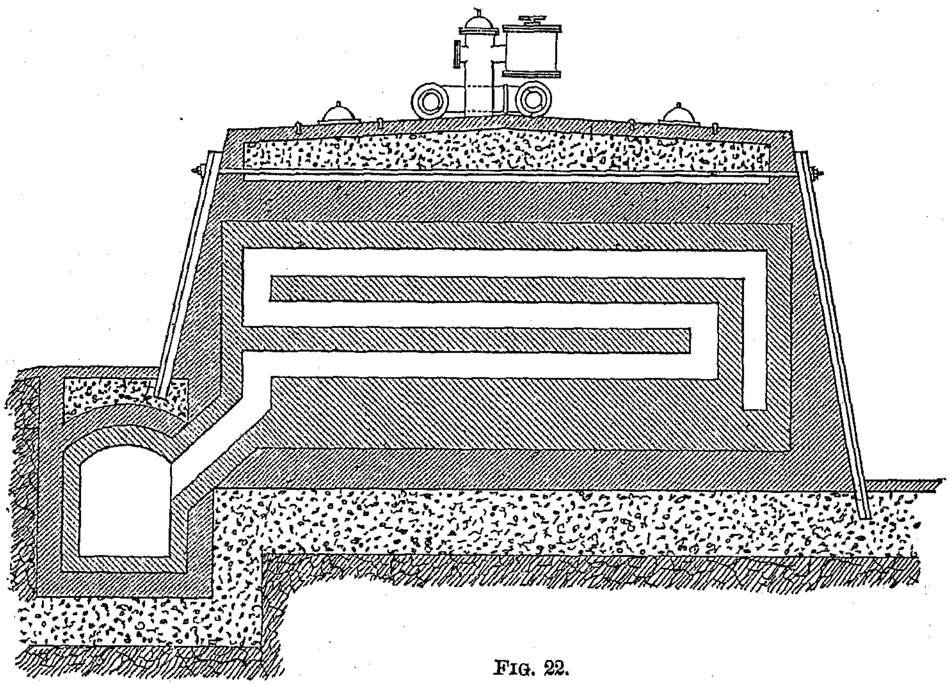


FIG. 22.

It has been found that the extraction of the gas from the ovens by artificial means (say a Beal's exhauster, similar to those used in gas-works) is more regular, and therefore preferable to extraction by the natural draught of the chimney only, as the latter varies often according to wind and temperature.

When a charge is nearly finished and ready to be taken from the oven some trucks full of coal are placed ready on the rails going along on the top of the ovens and over the charging-holes. The two end doors are then opened. The mass of coke, measuring about 30 feet long by 2 feet thick and 6 feet high, is pushed out at the

SIEMENS-CARVES OVEN.

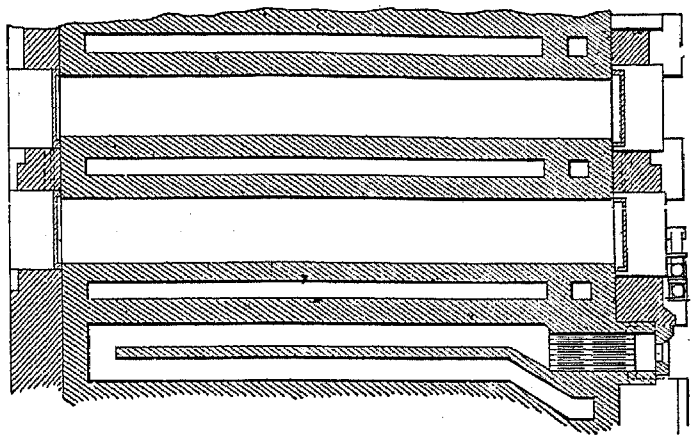


FIG. 23.

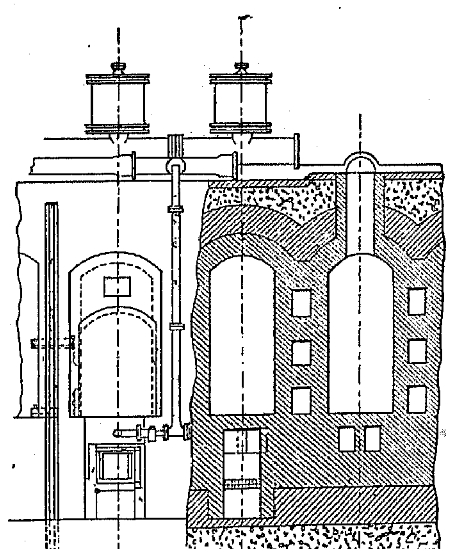


FIG. 24.

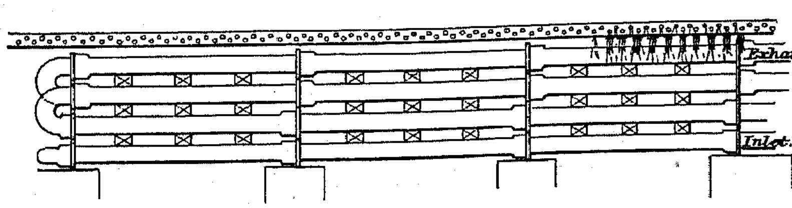


FIG. 25.

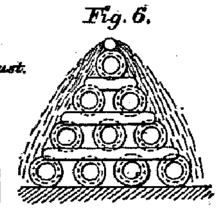


FIG. 26.

back of the oven and upon the bank by means of a ram or piston, worked by a portable steam-engine running on rails in front, and similar to the well-known arrangement used with the Coppée ovens. The ram can be brought opposite to each oven in turn. The coke is then quenched as usual.

Immediately after the discharge of an oven the tops are opened, and the coal from trucks emptied into the hot oven and raked level. The doors and top openings are then closed again, and the process begun afresh. The operations of discharging and refilling, when well conducted, need not take more than ten or fifteen minutes.

The Terrenoire Company, in France, originally introduced this process in the year 1867, and has since then, from time to time, increased the number of ovens at their different works; but their proportions and method of construction have, during these years, undergone continued and considerable alteration and improvement.

Experience has shown that a great deal depends upon the dimensions of the vertical sections of these ovens. At the outset they were made too wide and too low, and the density or hardness of the coke was, under such circumstances, not such as was desirable; but from a width of 6 feet 6 inches, they have been gradually reduced, until at present they are 2 feet only, with a height of at least 6 or 7 feet.

The effect upon the hardness of the coke by the reduction in width has been quite beneficial. M. Jouguet, the director of the Bessèges works of the Terrenoire Company, gives the following table, showing resistance to crushing of six different kinds of coke, experimented on by him in 1880:

[Resistance per square centimeter in kilograms.]

	Kilograms.
1. Coke from Carvès ovens of 70 centimeters width ($27\frac{9}{16}$ inches)	66.46
2. Coke from Carvès ovens of 66 centimeters width (26 inches)	79.72
3. Coke from Carvès ovens of 50 centimeters width ($19\frac{11}{16}$ inches)	92.32
4. Coke from bee-hive ovens of 50 centimeters width	43.92
5. Coke from Belgian ovens of 50 centimeters width	53.12
6. Coke from Coppée ovens of 50 centimeters width	80.50

Nos. 1 to 3 show clearly that the hardness of the coke increases as the width of the oven or the thickness of the layer of coal treated decreases.

The time required for each charge varies according to the description of coal and the dimensions of the oven. In ovens of a width of 2 feet a charge is finished every 48 hours; in ovens of a width of 3 feet 60 to 70 hours are required.

At the Bessèges works steam is produced to the extent of about 45 pounds and of $4\frac{1}{4}$ atmospheres pressure per hour and per ton of coal coked, and under more favorable circumstances it is thought 59 pounds of steam should be obtained. As at Bessèges 1,400 kilograms (3,080 pounds) of coal are carbonized per oven and per 24 hours, it follows that, taking about $17\frac{1}{2}$ pounds of steam as necessary to produce one horse-power per hour, each oven gives about $3\frac{2}{3}$ horse-power of motive power, and could be driven to about $4\frac{2}{3}$ horse-power. (*a*) At Bessèges all the machinery required in the manufacture of coke and its by-products is now being driven by steam raised in this way, and there remains a large surplus, which is used in the blowing-engines for the Bessemer process for lifting charges to furnaces, etc.

At Saint-Étienne, in France, coke was for many years made upon a somewhat similar system, but the manufacture was discontinued in favor of Carvès' system, which gives greatly superior results in every way.

There can be no doubt that much of the prejudice existing against these ovens and this system as the results of early trials was just. The latter results also seem to indicate that the disadvantages of the earlier ovens have been removed. The present increased heating surface of the ovens is the principal cause of this change for the better; for whereas in the first ovens the heating surface per ton of coal charged was only 18 square feet, and was applied exclusively under the sole of the oven, in the last ovens the heating surface per ton of coal charged amounts to about three times as much, namely, 54 feet, and surrounds almost entirely the charge of coal, which is much thinner than before.

The cost of ovens varies considerably, according to local circumstances. On solid ground much less expense is occasioned in foundations.

I annex a translation of the actual expense incurred in constructing the last battery of a hundred ovens at Terrenoire, which are each 19 feet $8\frac{3}{16}$ inches (6 meters) long, 2 feet 6 inches (0.73 meter) wide, and 5 feet 7 inches (1.70 meters) high. The length of the ovens but for local circumstances would have been greater, as thereby the power of production per oven is increased, with almost no increased expense of working. Each of these ovens takes a charge of 5 tons of coal, and produces at the rate of from 1,100 to 1,400 kilograms (22 to 28 hundred-weight) of coke per 24 hours, according to the quality of coal used and the quality of coke required. The time occupied by one operation with this size of oven is from 60 to 72 hours.

a Or, to express it more clearly, a battery of 100 ovens will furnish steam for about 400 horse-power over and above the making of the coke and the rendering of the by-products.

COST OF CONSTRUCTING ONE HUNDRED COKE OVENS ON THE CARVÈS SYSTEM AT TERRENOIRE, FRANCE.

[One cubic meter=1.3 cubic yard.]

Masonry.	Number of cubic meters.	Price per cubic meter.	Total.
		Francs.	*Francs.*
1. Ovens complete, including flues:			
Digging out foundation	660.87	2.00	1,321.75
Concrete	803.75	12.00	9,645.00
Rough stones	100.00	11.00	1,100.00
Red brick	1,828.82	25.00	45,720.50
Fire-brick	1,358.00	90.00	122,220.00
2. Discharging platforms:			
Digging out foundation	32.00	2.00	64.00
Rough stones	6.40	11.00	70.40
Dressed stone	6.40	60.00	384.00
Red brick	79.40	25.00	1,985.00
3. Four chimneys:			
Digging out foundation	94.01	2.00	188.00
Rough stones	77.10	11.00	848.10
Red brick	340.08	25.00	8,502.00
Fire-brick	16.28	90.00	1,465.20
4. Flues to Beal's exhauster, pumps, and condensing pipes:			
Digging out foundation	274.55	2.00	549.10
Rough stones	119.49	11.00	1,314.40
Red brick	28.45	25.00	711.25
5. Engine-house:			
Digging out foundation	277.81	2.00	555.60
Concrete	55.12	12.00	661.45
Rough stones	143.85	11.00	1,582.35
Red brick	18.72	25.00	468.00
6. Foundation for engine:			
Digging out foundation	54.93	2.00	109.85
Concrete	27.48	12.00	329.75
Red brick	18.59	25.00	464.75
Dressed stone	3.36	60.00	201.60
7. Foundations for Beal's extractors:			
Digging out foundation	3.70	2.00	7.40
Concrete	2.69	12.00	32.30
Rough stones	3.24	11.00	35.65
Dressed stone	1.60	60.00	96.00
8. Pump foundations:			
Digging out foundation	1.65	2.00	3.30
Concrete	1.65	12.00	19.80
Rough stones	3.04	11.00	33.45
Dressed stone	1.86	60.00	111.60
9. Masonry under engine floor:			
Rough stones	2.23	11.00	24.55
Red brick	3.03	25.00	75.75
10. Masonry for Field's boilers:			
Digging out foundation	88.34	2.00	176.70
Rough stones	27.78	11.00	305.60
Red brick	36.89	25.00	922.25
Fire-brick	11.11	90.00	999.90
11. Feed-water tank:			
Red brick	2.25	25.00	56.25
12. Scrubbers:			
Digging out foundation	17.01	2.00	34.00
Rough stones	26.47	11.00	291.15
Red brick	8.43	25.00	210.75
13. Settling tank:			
Digging out foundation	106.10	2.00	200.20
Rough stones	26.32	11.00	289.50
Red brick	1.75	25.00	43.75
14. Condensing tank:			
Digging out foundation	70.68	2.00	141.35
Rough stones	1.48	11.00	16.30
Red brick	0.68	25.00	17.00
15. Other tank:			
Digging out foundation	3.68	2.00	7.35
Rough stones	23.15	11.00	254.65
Red brick	1.71	25.00	42.75
16. Tar reservoir:			
Digging out foundation	3.67	2.00	7.35
Rough stones	11.04	11.00	121.45
Red brick	0.75	25.00	18.75
17. Tank for ammoniacal water:			
Digging out foundation	3.67	2.00	7.35
Rough stones	12.23	11.00	134.55
Red brick	0.75	25.00	18.75
18. Woodwork, etc., for engine-house:		*Francs.*	*Francs.*
Timber for house and shafting			800.00
Four windows and two doors			304.65
Painting			455.00
Glass			78.00
Tiles			208.00
Fixing			165.00

Railway lines, doors, and fittings.	Quantities.	Price per 100 kilograms.	Total.
	Kilograms.	*Francs.*	*Francs.*
19. Railway lines:			
Rails and chairs	10,780	25.00	2,695.00
Stone underchairs	15,050		210.00
20. Doors:			
Cast-iron	30,380	25.00	7,595.00
Wrought-iron	5,200	30.00	1,560.00
21. Fittings:			
Wrought-iron	33,334	30.00	10,000.20
22. Discharging-machine or ram:			
Machine for discharging coke from ovens.			12,000.00
Sleepers	120	7.00	840.00
Rails	12,100	25.00	3,025.00
Chairs	2,250	25.00	562.50
Laying lines and fixing machinery			415.00
23. Apparatus used in collecting the by-products:			
Pipes supporting the valve-boxes, cast-iron.	21,000	25.00	5,250.00
Pipes connecting the valve-boxes, cast-iron.	2,490	25.00	622.50
Valve-boxes with covers, cast-iron	19,000	25.00	4,750.00
Valves with rods and keys, cast-iron.	1,000	25.00	250.00
Cocks, cast-iron	3,700	25.00	925.60
Nozzles, cast-iron	2,900	25.00	725.00
Furnace fronts and doors, cast-iron	35,700	25.00	8,925.00
Grate-bars, cast-iron	13,200	25.00	3,300.00
Plugs for top charging holes, cast-iron.	9,000	25.00	2,250.00
Gas exhaust pipes, cast-iron	11,500	25.00	2,875.00
Pipes conducting gas back under furnace, cast-iron.	9,000	25.00	2,250.00
Pipes receiving gas from the ovens, cast-iron.	28,000	25.00	7,000.00
Return gas-pipes to furnace, cast-iron.	8,000	25.00	2,000.00
One steam-engine, 15-inch cylinder, 31½-inch stroke.			15,000.00
Two field boilers, with fittings			8,000.00
Two pumps			2,000.00
Two Beal's extractors			5,000.00
Twelve scrubbers			12,234.15
One water-tank	420	50.00	210.00
Two safety-boxes, cast-iron	2,600	25.00	500.00
Two safety-boxes, cast-iron	1,400	25.00	350.00
Lead for joints	7,698	40.00	3,077.20
Six wrought-iron tanks, each 60 cubic meters capacity.	17,940	65.00	12,831.00
Pulleys, cone pulleys, bearings, gearing, and pinions for shafting, cast-iron.	2,547	100.00	2,547.00
Brass for bearings	230	4.50	1,035.00
Wrought-iron work for shafting	1,395	100.00	1,395.00
Eleven leather belts	297	8.00	2,376.00
Bolts	1,828	80.00	1,462.40
Pipes between furnaces and exhausters and *vice versa*, pipes for pumps, steam-pipes, feed-pipes, pipes for cooling water, etc., cast-iron.	62,000	25.00	15,500.00
Packing for joints, etc., sundry expense (oil, coal, felt, laces, etc.).			2,400.00
24. Scrubbers:			
Timber-framing	2.5 cub. m.	140.00	350.00
Quartz	151,600	7.00	1,061.20
25. Laying down of pipes forming integral parts of ovens and other apparatus.			9,800.00
26. Sundries			500.00
Total			384,884.30

The table shows altogether, say, about £15,500, or £155 per oven complete, with all machinery and apparatus for collecting the by-products, and including rail connections, coke platforms, etc.

The repairs of these ovens are—care and completeness in their first erection being presupposed—very low. At Terrenoire they are given as three halfpence per ton of coke, which will compare very favorably with those incurred in other systems. At Bessèges, where there is a lot of very old ovens, the cost of repairs, materials and labor included, stands now, according to the very exact accounts of M. Jouguet, at under fourpence per ton of coke made. The principal repairs are the renewal of fire-bricks over the grates in the sole of the ovens and the renewal of the cast-iron doors, which crack and break after a time. The last lot of ovens established at Bessèges, in August, 1878, had not in 1880 required the slightest repairs. Much, of course, depends upon the temperature employed during the process, which, in its turn, depends upon the kind of coal coked and the dimensions of the ovens. Narrower ovens, with more rapid carbonization, are subject to higher temperatures, and consequently to greater extremes of temperature and liability to injury. Experience goes to show that after the first two years or so each oven may on an average lose one or two days a year through repairs. It will therefore be seen that although the original cost of the ovens is large, the outlay for repairs is very much smaller than in the bee-hive and others.

At Terrenoire the number of work-people employed on a battery of 100 ovens, producing over 100 tons of coke per day, is 48 per 24 hours. This includes 2 foremen and 2 masons for repairs. Their wages are 184½ francs, or, say, £7 10*s.* per day, being at the rate of, say, 1*s.* 6*d.* per ton of coke for labor.

On the other hand, the cost of producing the coke is given by M. Jouguet, of Bessèges, as about 3 francs, or, say, under 2*s.* 6*d.* per ton, including all labor and materials and the cost of repairs.

Mr. Simon claims the following advantages for these ovens, viz:

1. Greater yield of coke by about 10 per cent.
2. Greater purity of coke.
3. A yield of about 4*s.* worth of useful by-products per ton of coke.
4. An almost entire absence of smoke or noxious vapors.
5. In comparison with any other existing system of coke-ovens, equal facilities for utilizing the heat, and a reduced cost for repairs.

The following table shows the results obtained by the ovens at Bessèges during the last twelve years, and up to the end of 1879: (*a*)

AVERAGE RESULTS OF OVENS ON THE CARVÈS SYSTEM AT THE BESSÈGES WORKS OF THE TERRENOIRE COMPANY.

	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.
Coal consumed.....tons..	4,849	14,329	14,641	13,886	14,632	14,215	26,998	30,057	35,451	45,881	44,754	41,797	46,900
Number of coke ovens.....	25	25	25	25	25	25	53	53	(*)	85	85	(†)	96
Coke produced.....tons..	3,075	9,054	9,575	9,272	9,760	9,297	18,820	20,763	24,462	31,720	31,065	29,166	33,092
Production of coke per oven and per year.....do....	120	365	385	375	330	375	355	390	386	373	365	355	344
Tar obtained.....do....	74	263	296	327	267	228	458	562	585	778	766	851	1,099
Ammoniacal liquor obtained.....do....	60	1,073	1,120	1,113	979	794	1,683	3,256	3,214	4,450	4,366	3,995	4,393
Sulphate of ammonia made‡.....do....	....	56	60	50	46	42	67	113	97	158	172	122	....
Yield of coke according to books.....per cent..	63.5	63.2	65.3	66.7	66.7	65.2	69.7	69.0	69.0	69.9	69.4	69.8	70.5
Yield of coke after deduction of water contained in washed coal, per cent.	67.2	67.2	69.8	69.8	76.5	69.5	73.0	73.0	73.4	74.4	73.8	74.2	§ 75
Tar per ton of coal.....kilograms..	15.6	17.6	20.0	17.9	18.3	16.0	17.0	18.6	16.5	17.1	17.1	20.4	23.4
Tar per ton of coke.....do....	24.3	29.0	30.0	25.0	27.4	24.7	25.7	27.1	24.0	24.5	24.7	29.2	33.2
Ammoniacal liquor per ton of coal.....do....	....	75.8	76.0	73.0	66.9	55.7	62.5	108.5	91.0	98.3	98.2	95.6	93.6
Ammoniacal liquor per ton of coke.....do....	....	118.0	117.0	109.0	100.4	85.5	94.1	157.0	132.0	140.6	141.8	137.0	132.7
Small fuel consumed under grates per ton of coke made, kilograms.	....	46.0	28.0	16.0	17.0	18.6	20.3	21.4	22.7	11.5	11.0	15.2	15.9

* During the first eight months of 1875, 53 ovens were at work. During the last four months of 1875, 85 ovens were at work.

† During the first four months of 1878, 85 ovens were at work. During the second four months of 1878, 53 ovens were at work; during the last four months of 1878 96 ovens were at work.

‡ The making of sulphate of ammonia was given over in December, 1878; since then the ammoniacal liquor is sold direct.

§ Yield calculated after deduction of the water contained in the coke as well as of that contained in the coal after it is washed.

In all industries the subject of waste is a most important one, and in many the profit of to-day is from the waste of ten years ago, which better methods have saved. Our resources of coal to-day may be enormous, and the need of economy not apparent, but every waste of these resources is the act of a spendthrift. Dr. Angus Smith says in one of his yearly reports that "the present method of making coke in England has all the appearance of roughness and savagery which extravagance always produces". He might extend the charge to coking in this country.

a There were at the close of 1882 three works in France using the Carvès system—Tamaris, Terrenoire, and Bessèges. The total amount of coke produced by this system at these works is about 300 tons per day.

INDEX TO COKE.

A.

Q.

R.

S.